ALTERNATIVE FUELS FOR TRANSPORTATION - THE QUEST FOR THE SILVER BULLET…

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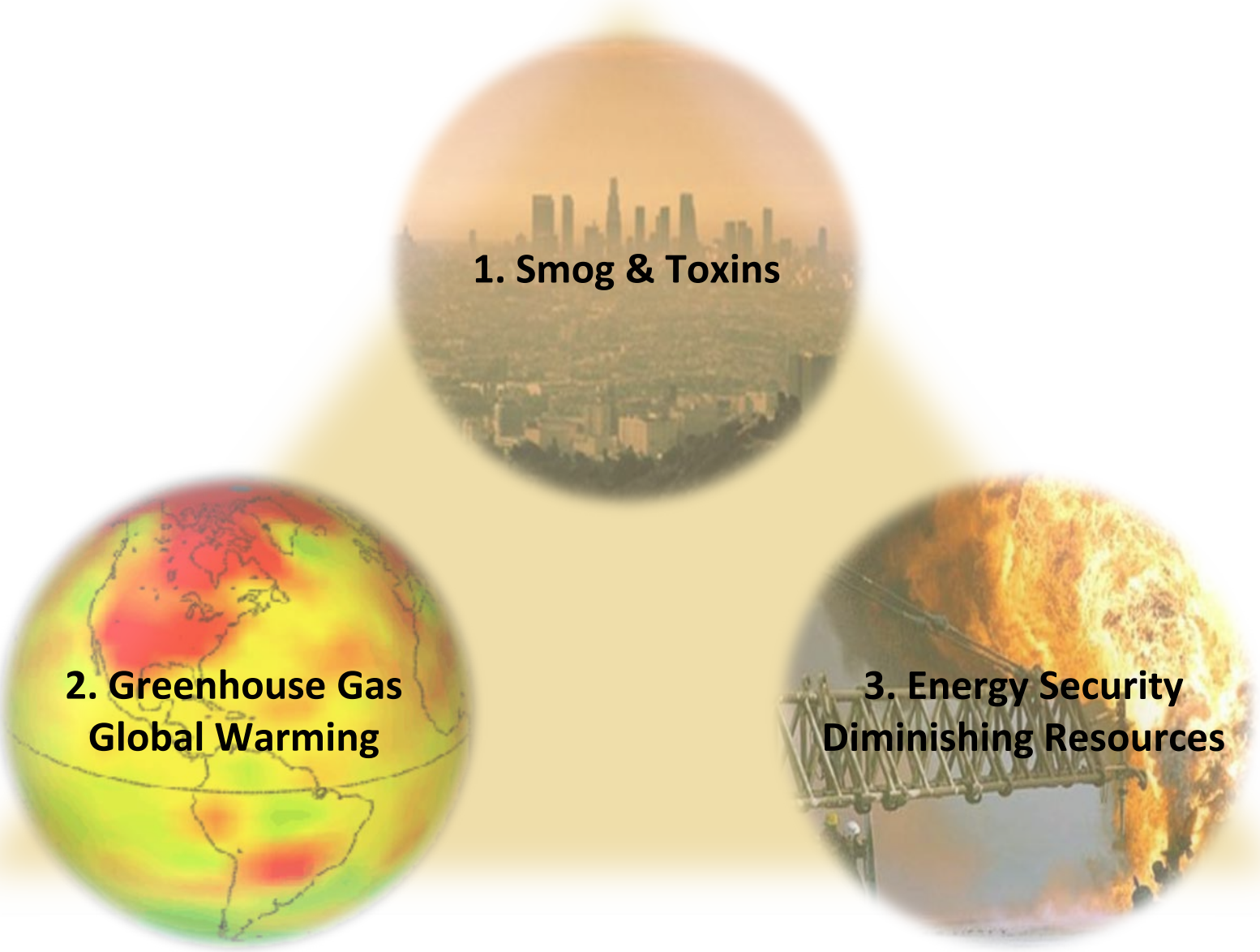
10TH INTERNATIONAL CONFERENCE ON ENGINES & VEHICLES

Capri, Italy

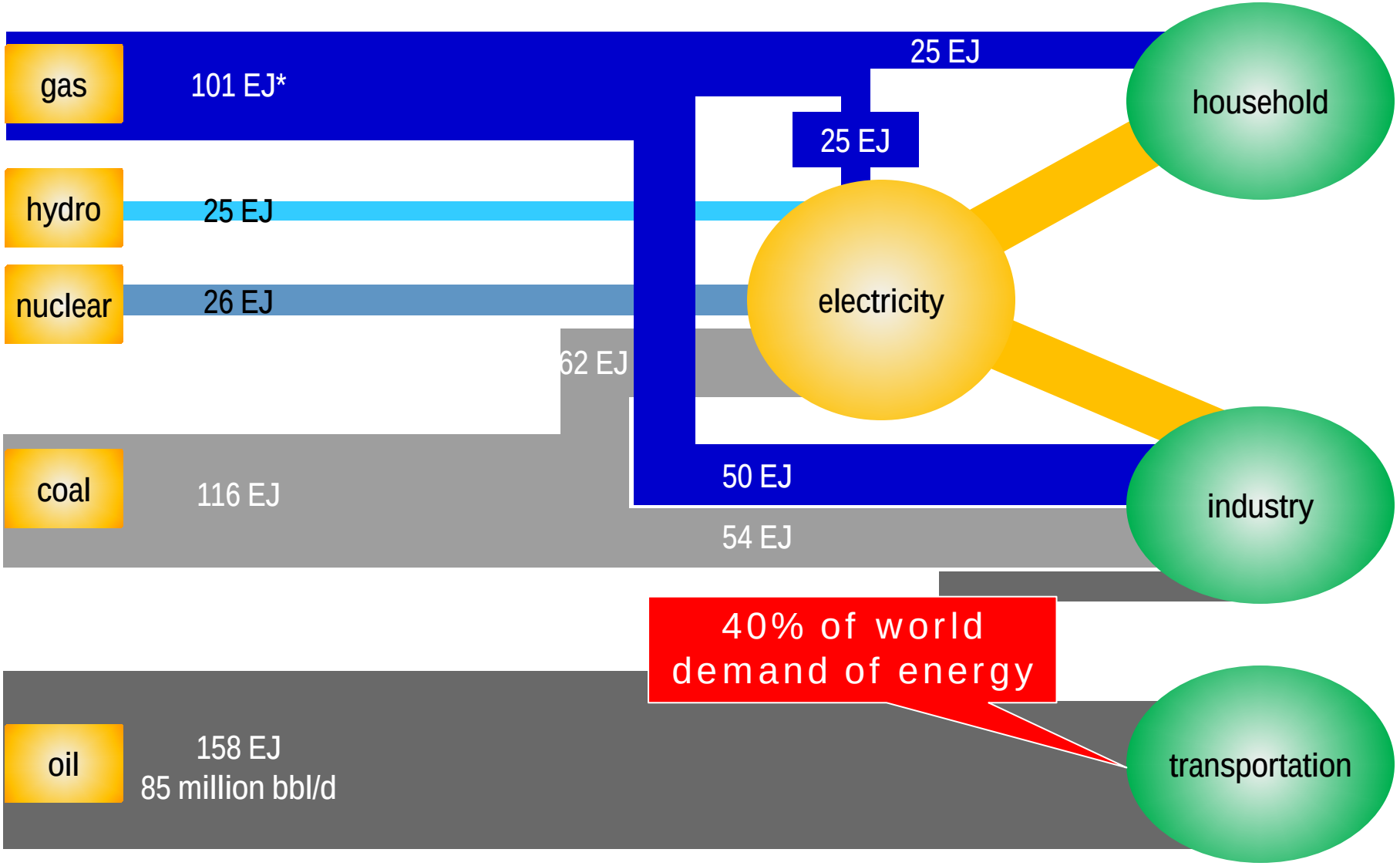
Sept. 14, 2011

What are drivers for improvements in transportation?

Three Mains Concerns



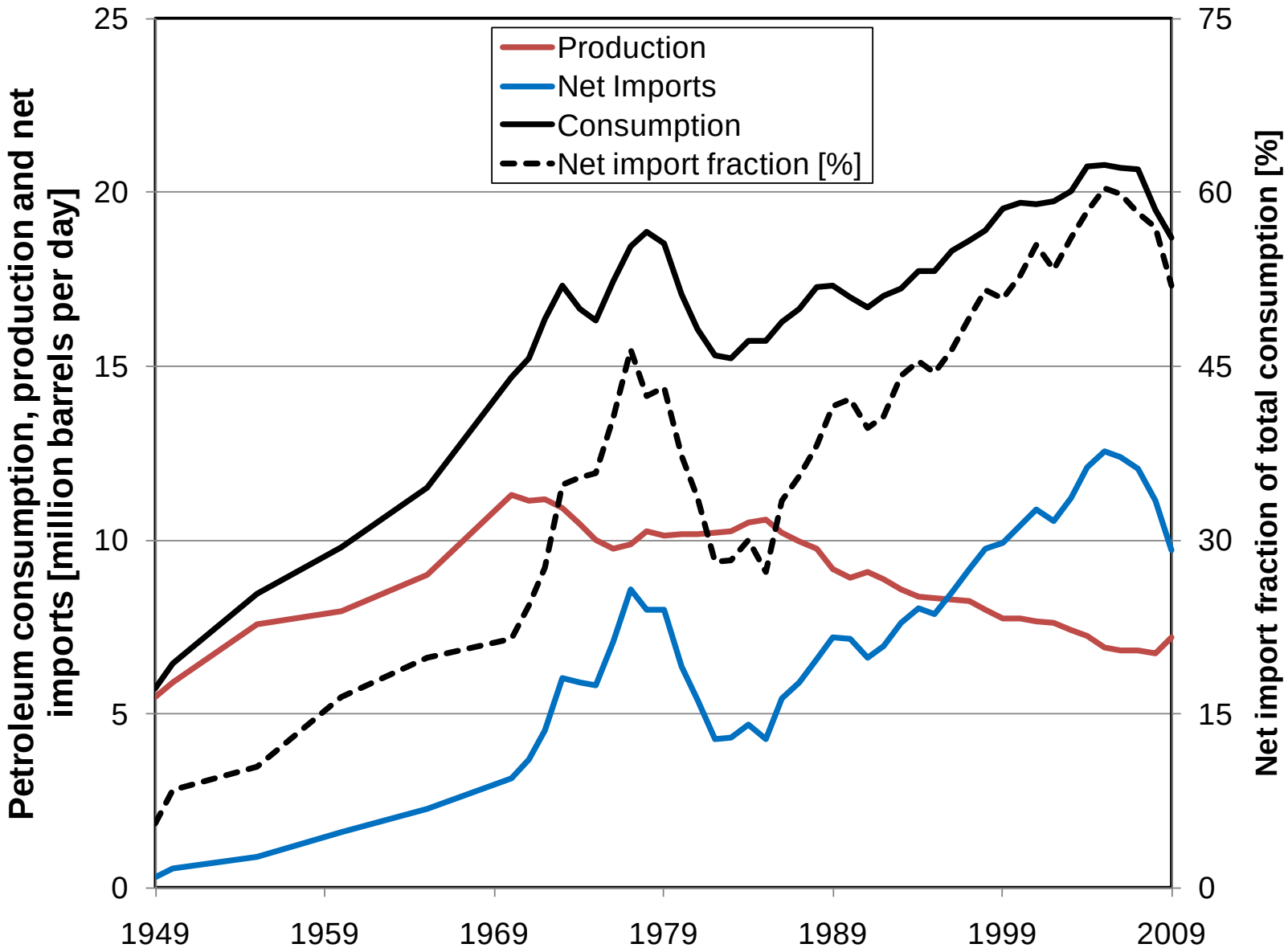
How do we use energy worldwide?



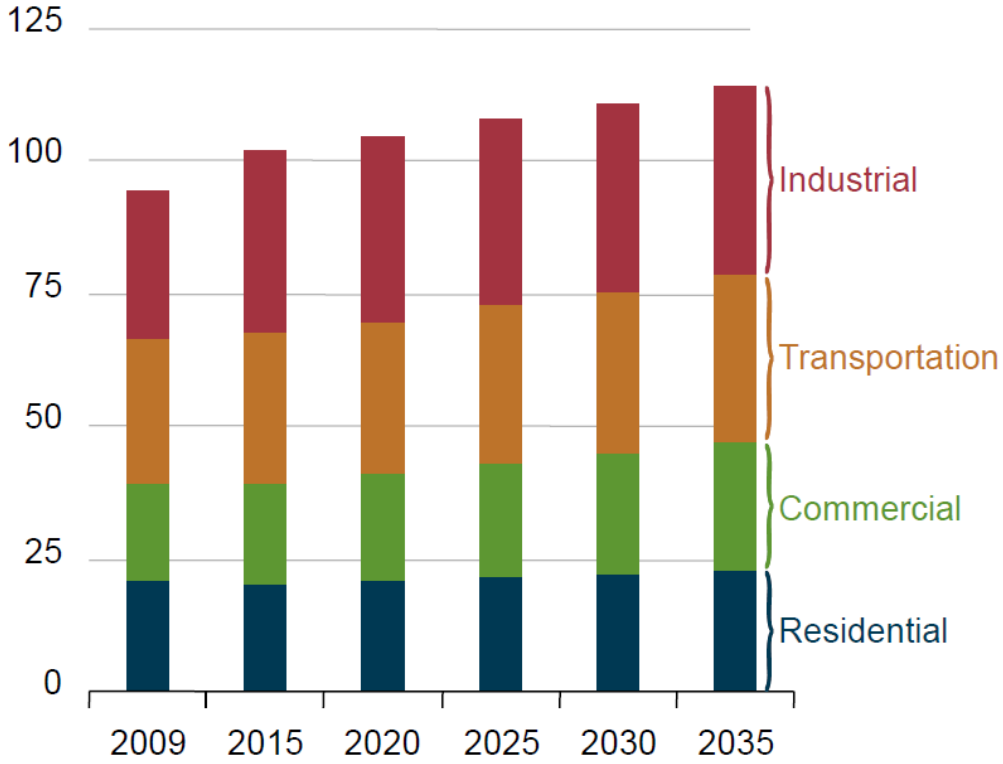
* EJ = Exajoules = 10^18 Joules

Source: BP energy stats & IEA

Crude oil production versus consumption in the US

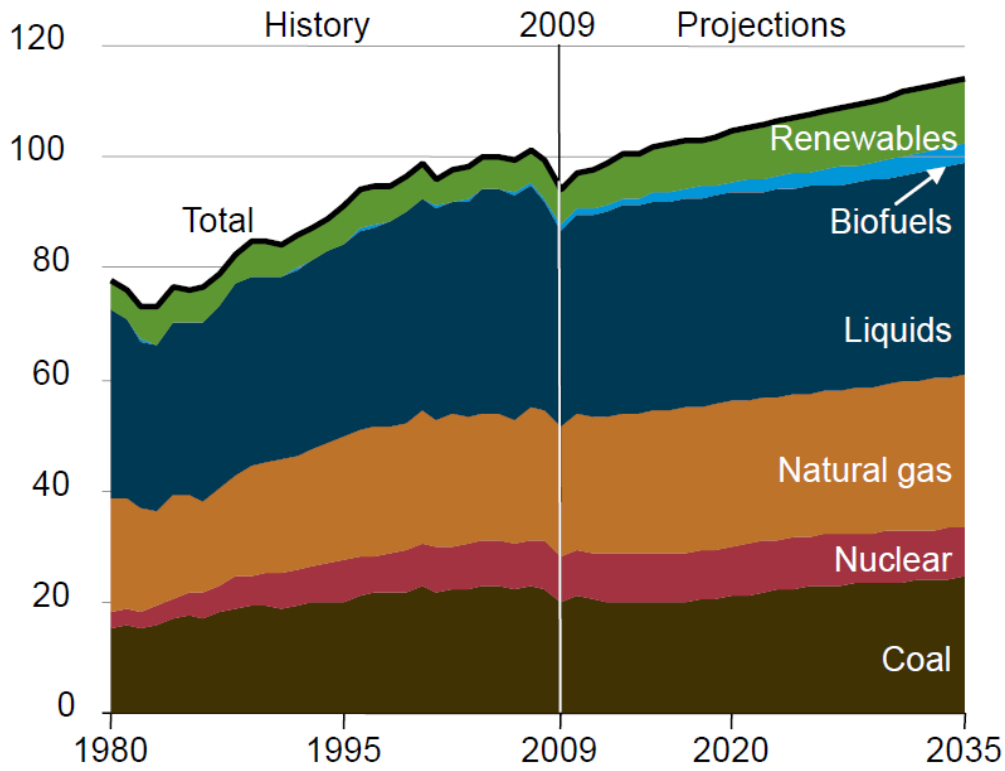


Energy use by sector and primary energy in the US



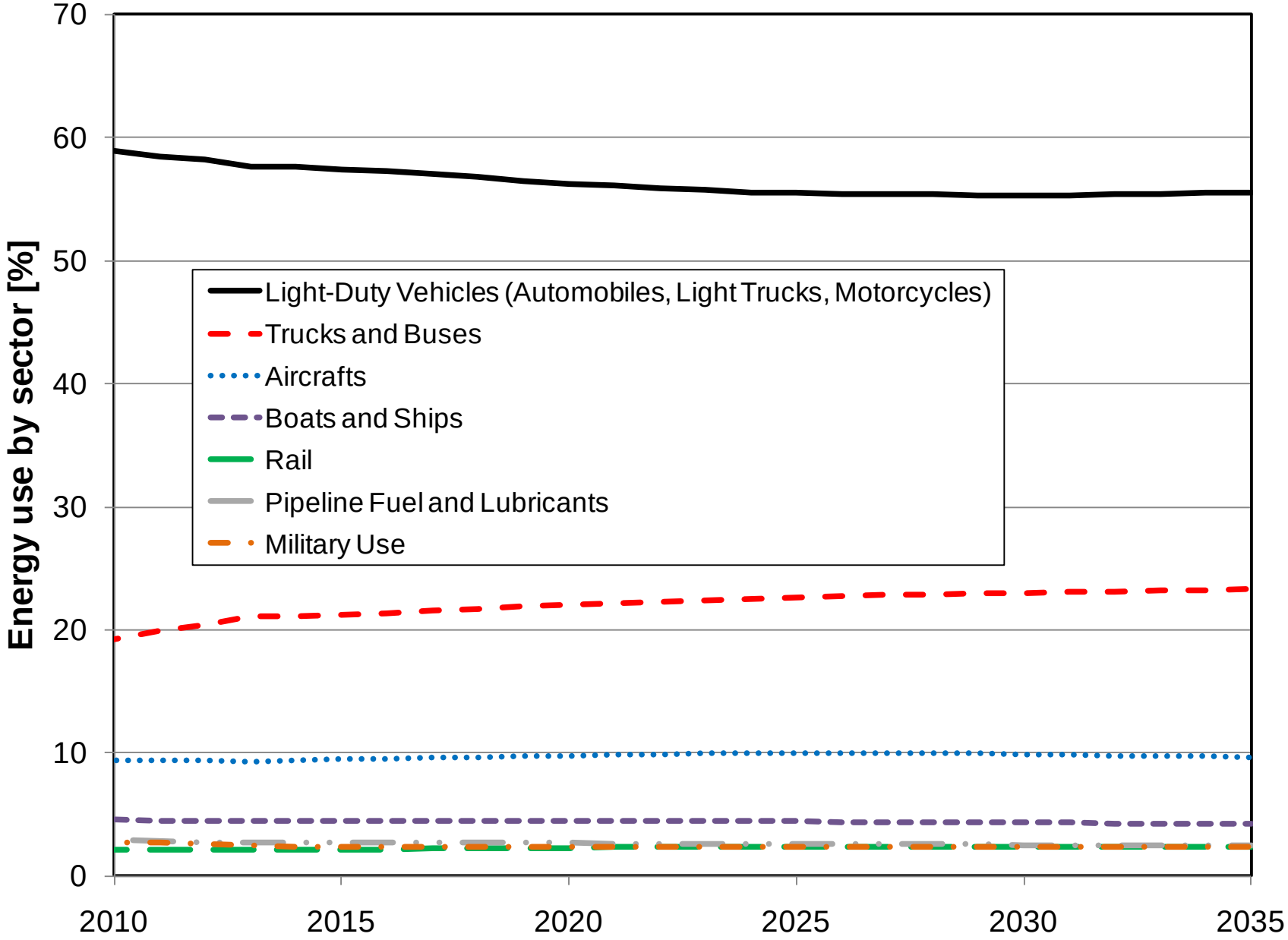
Primary energy use by end-use sector, 2009-2035 (quadrillion Btu)

Primary energy use by fuel, 1980-2035 (quadrillion Btu)



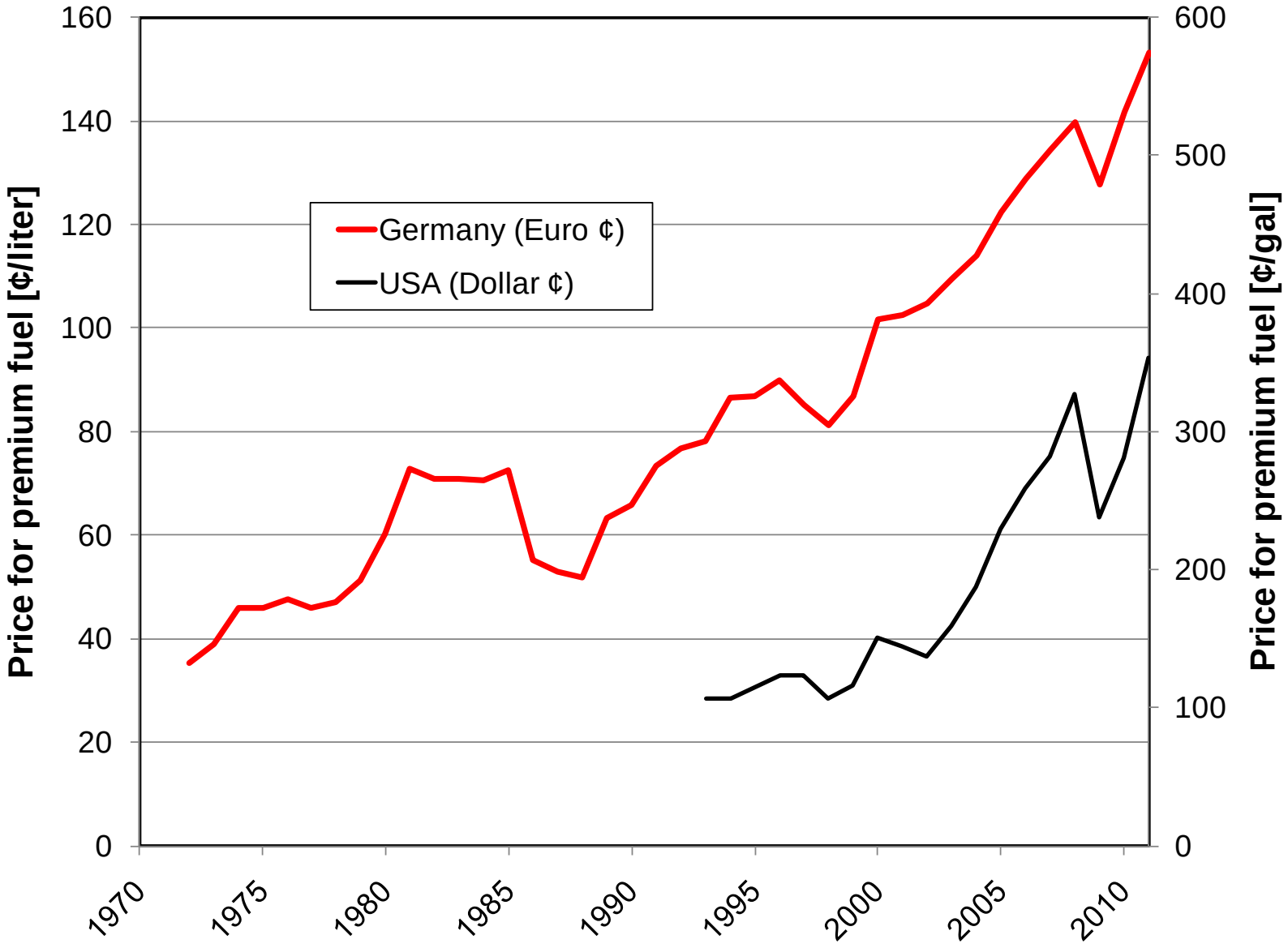
Source: US EIA Annual Energy Outlook 2011

Why light-duty applications?
Energy use by sector in the US



The end of cheap gasoline...

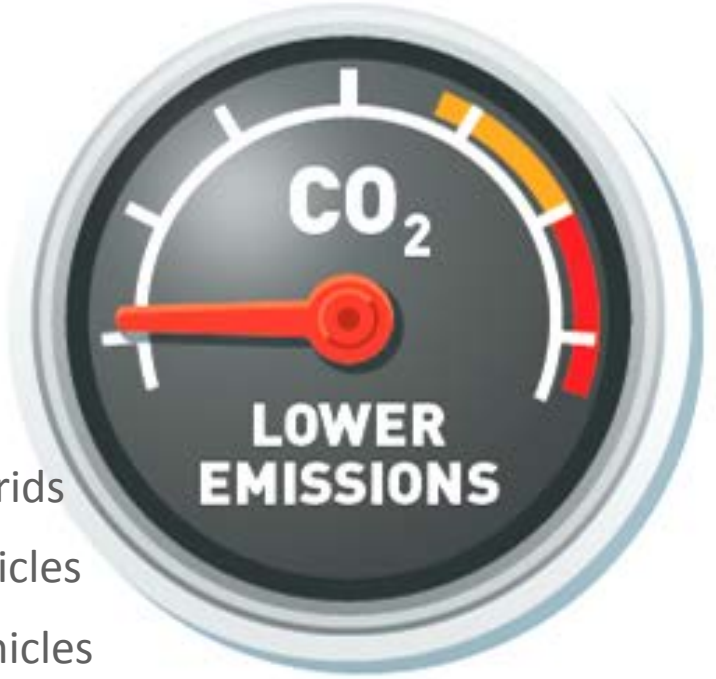
Historical prices for premium gasoline in Germany and the US



Reduction of petroleum consumption is inevitable…
Overview of promising pathways

- **Advanced engine technologies**
  - DI technologies
  - Downsizing and turbo-charging
  - Additional variabilities
  - HCCI/LTC
  - Aftertreatment systems

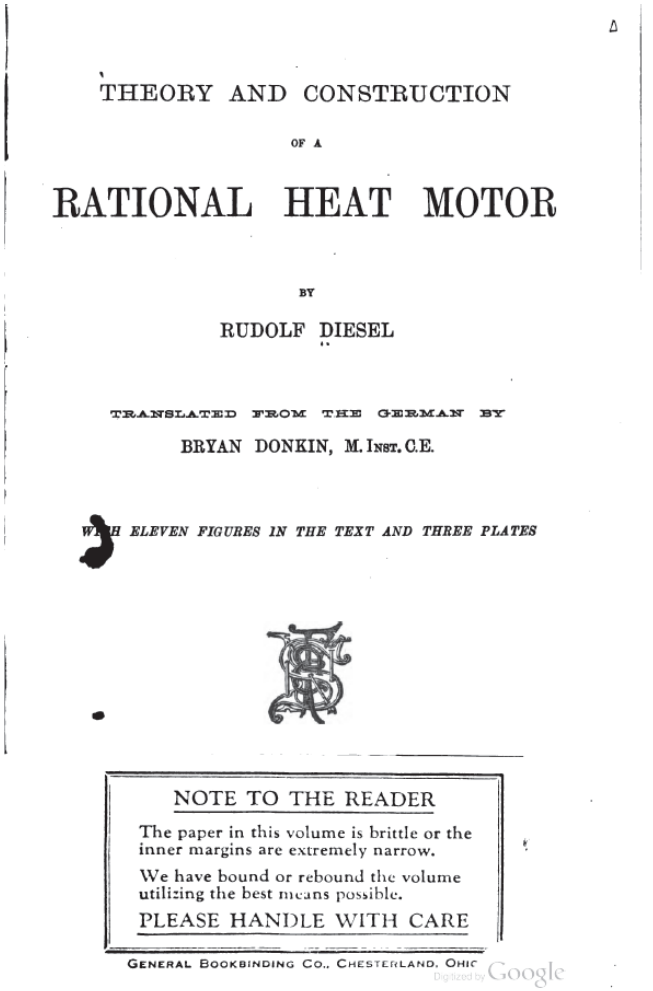
- **Powertrains**
  - Plug-in-Hybrids
  - Electric Vehicles
  - Fuel cell vehicles



- **Fuels**
  - Alcohol fuels
  - Diesel/Biodiesel
  - GTL/BTL/CTL
  - CNG/H2
  - …

Are Alternative Fuel Vehicles a NEW IDEA?

François Isaac de Rivaz of Switzerland designed first combustion engine that used a mixture of hydrogen and oxygen for fuel (1807)



THEORY AND CONSTRUCTION

OF A

RATIONAL HEAT MOTOR

BY

RUDOLF DIESEL

TRANSLATED FROM THE GERMAN BY

BRYAN DONKIN, M. Inst. C.E.

WITH ELEVEN FIGURES IN THE TEXT AND THREE PLATES

NOTE TO THE READER

The paper in this volume is brittle or the inner margins are extremely narrow.

We have bound or rebound the volume utilizing the best means possible.

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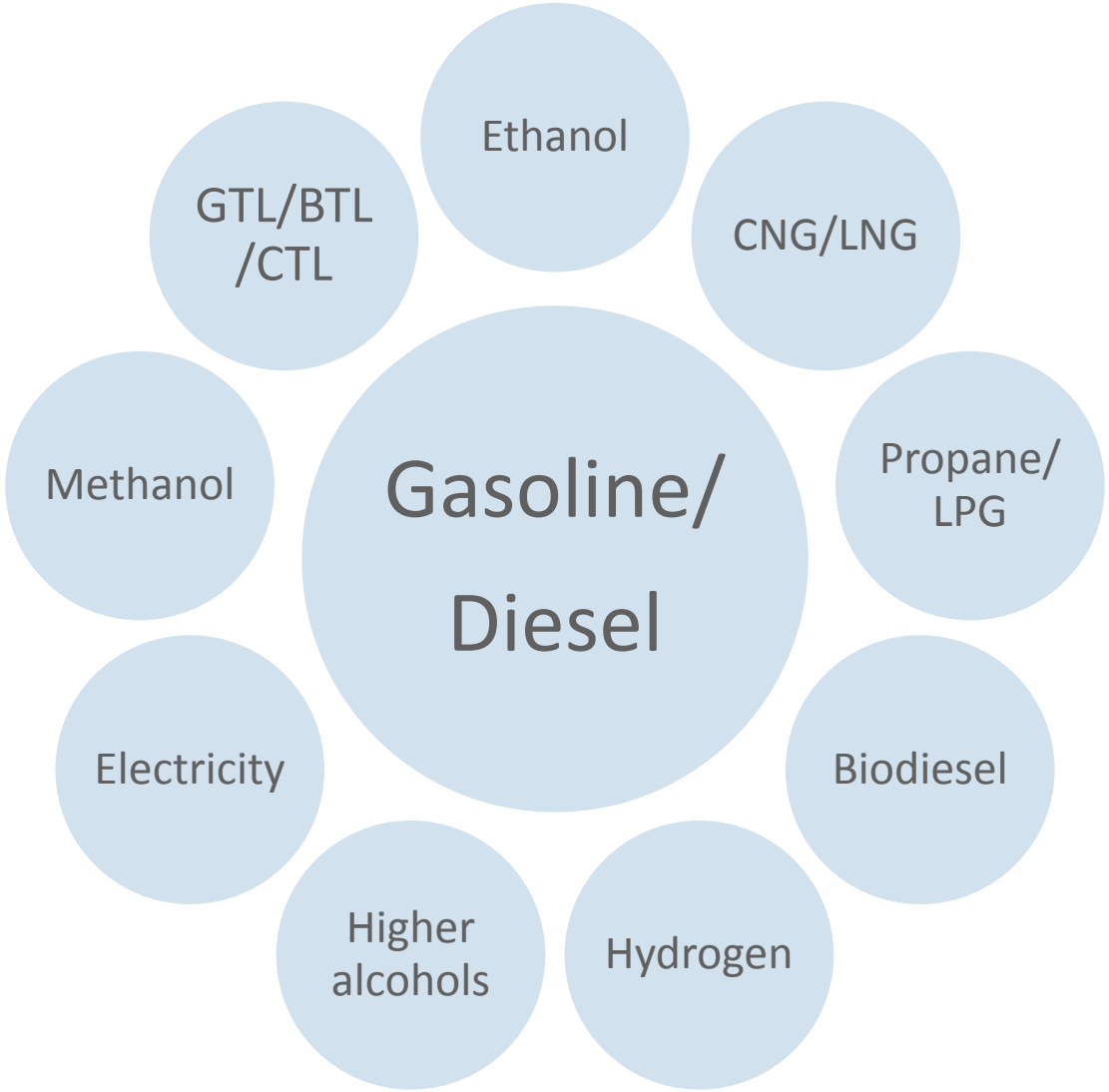
Ford Model T, was designed to run on ethanol

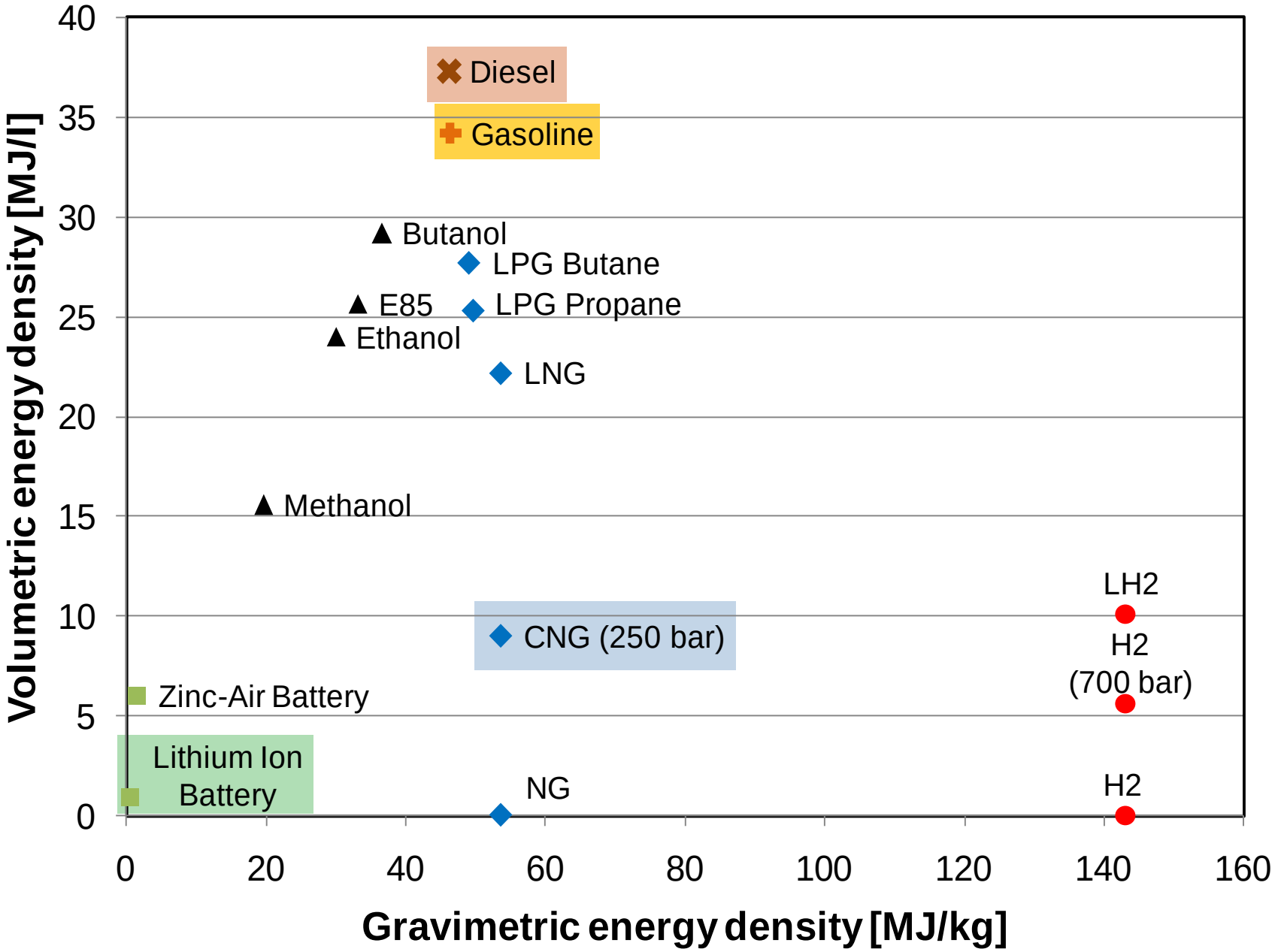
Rudolf Diesel including considerations for use of gaseous, liquid and solid fuels in 'Theory and Construction of a Rational Heat Motor' in 1894

What are the options?
Alternative fuels currently under investigation



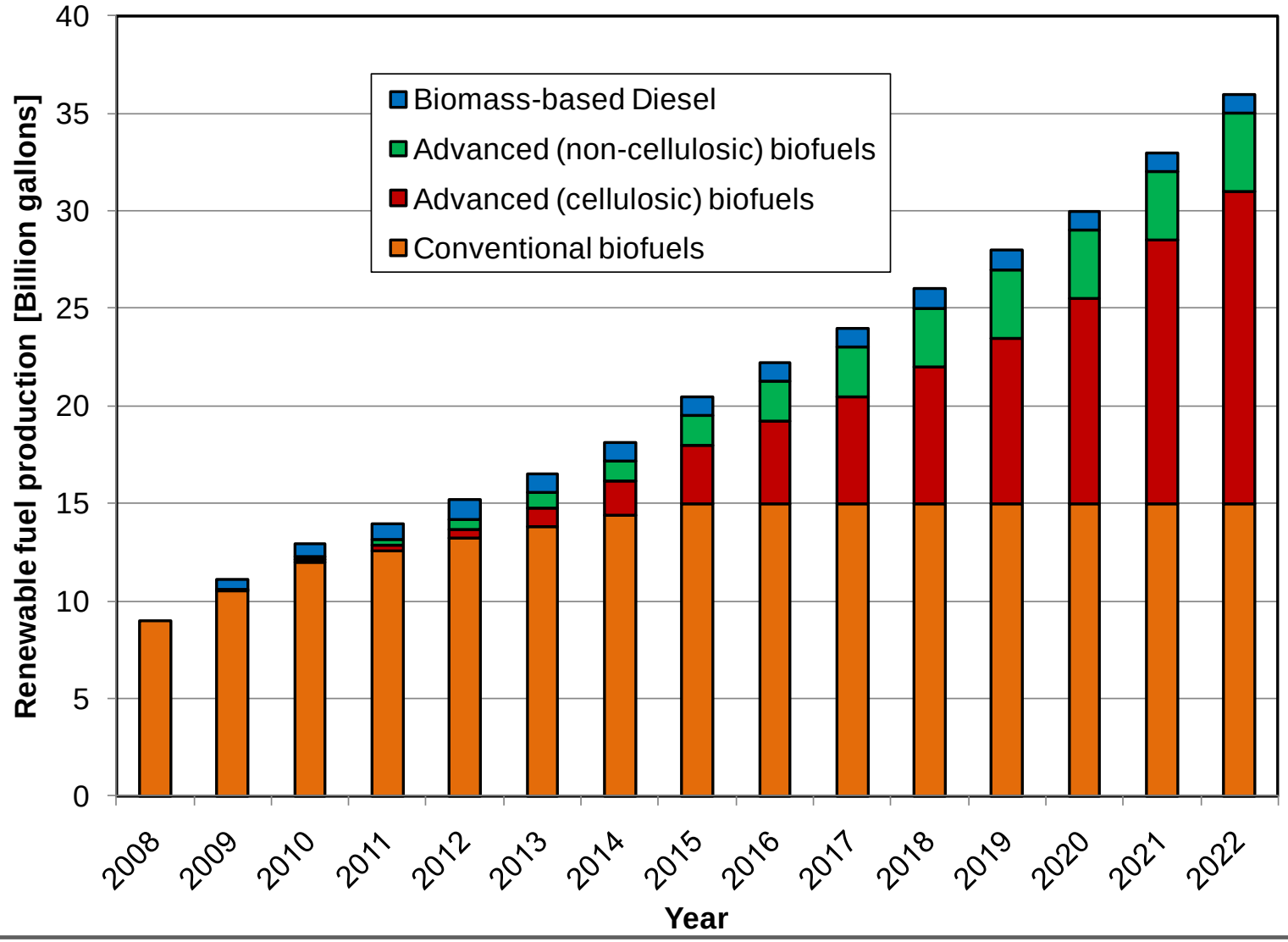
World-wide approx. 5% of the vehicle fleet are alt. fuel vehicles.

Energy carriers that compete with petroleum fuels



Political drivers

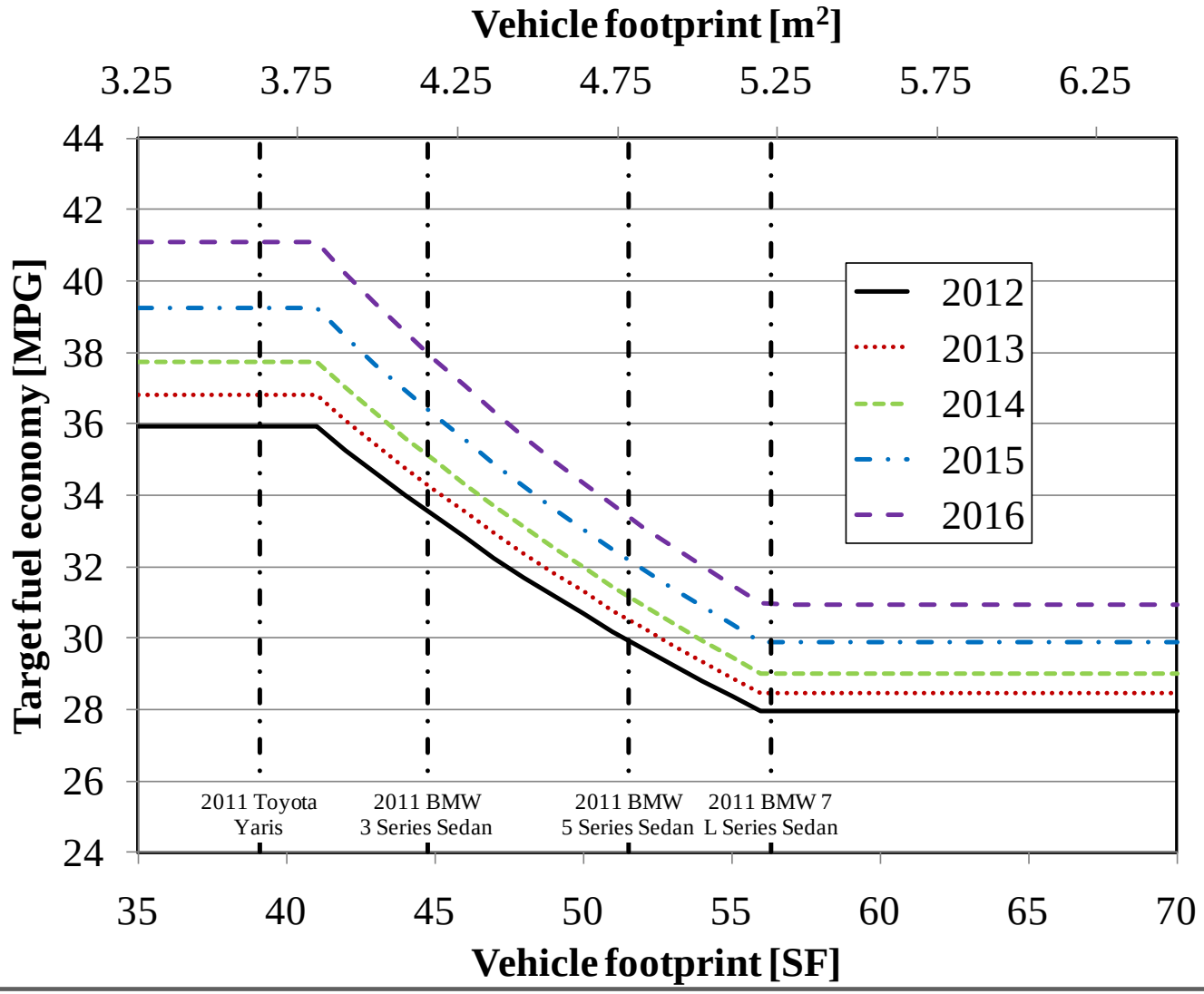
U.S. Renewable Fuels Standard (RFS)



Current level (2009) of renewable fuels accounts for approx. 4.3% of total consumption, 2022 target would be 7%.

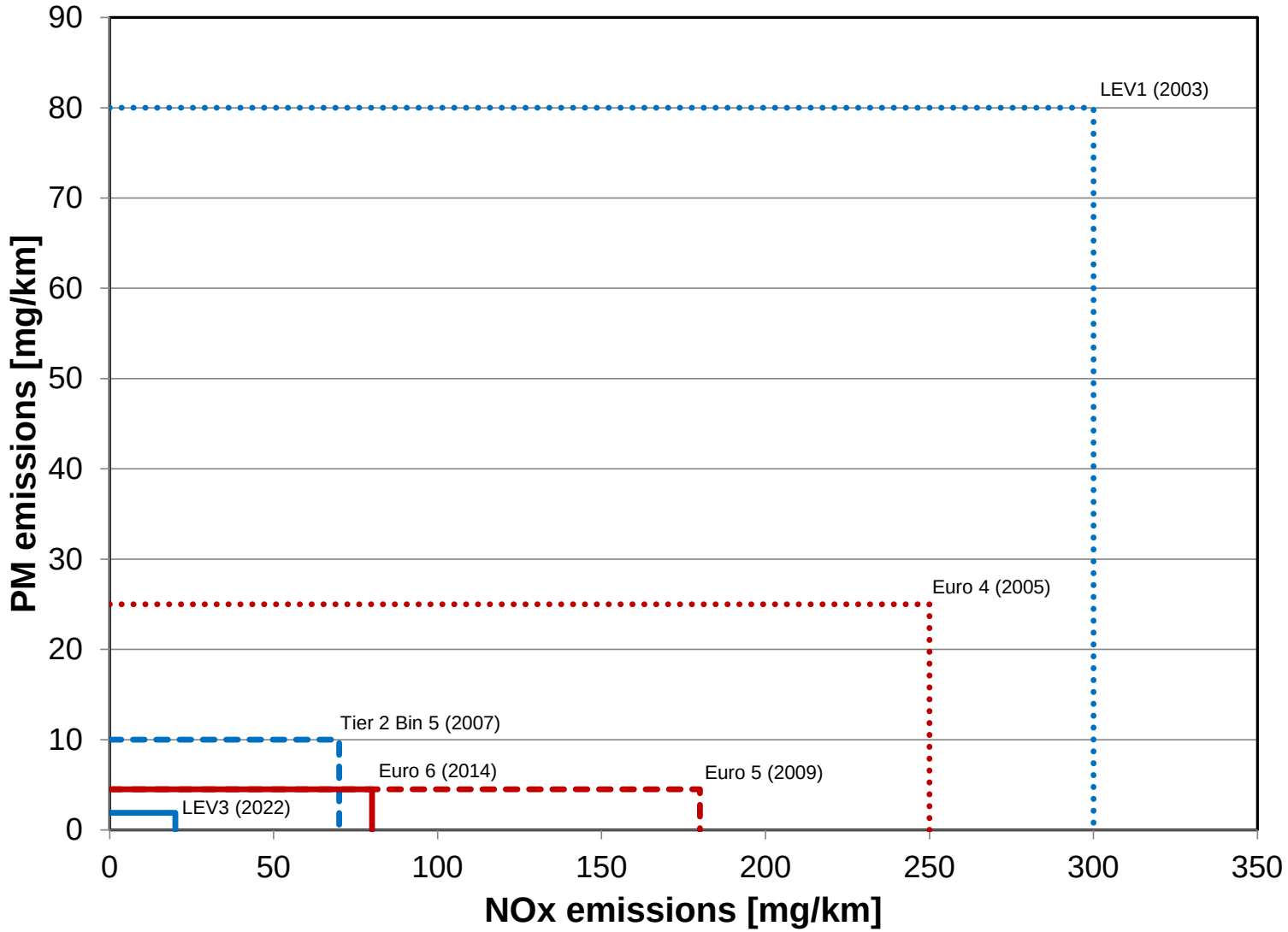
Political drivers

CAFE – Corporate Average Fuel Economy Targets



Even more stringent CAFE regulations in discussion beyond 2016

Political drivers
Emissions regulations



Extremely stringent PM regulations in discussion for LEV3 (3 mg/mi)

Political drivers
Other factors…

E15 waiver

EPA recently granted a waiver for the use of E15 in LD vehicles MY 2001 and newer

California ZEV Mandate

Initially a simple mandate for a certain fraction of OEM sales to be electric vehicles. Due to lack of vehicles mandate was designed flexible to be met by low emissions and hybrid electric vehicles. High volume OEMs required to sell 7,500 ZEVs in MY 2011-12 which increases to 25,000 in MY 2015-17.

Incentive program

Federal level a tax credit from $2,500 to $7,500 for PEVs. Additional state legislation to promote alternative fuels. Pending legislation (NAT GAS Act) with tax credits for natural gas vehicles and refueling providers

Barriers for alternative fuels
Infrastructure, infrastructure and infrastructure…

Public acceptance requires 10-30% of refueling stations to carry the alternative fuel*

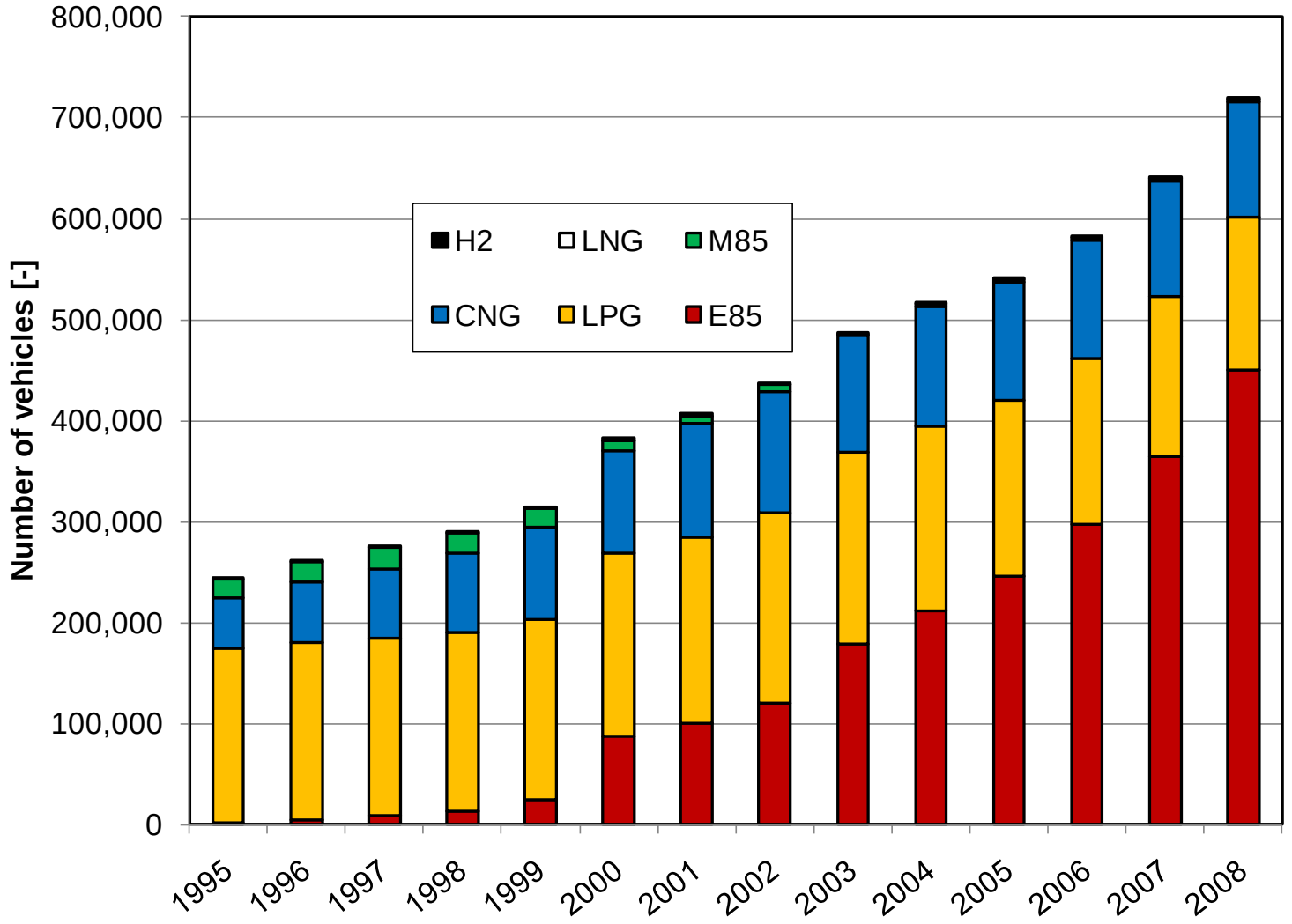
Today, there are about 170,000 gas stations in the US

Strong global, regional and local differences in infrastructure development

* Yeh, S. ‘An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles’. Energy Policy 35 (2007) 5865–5875

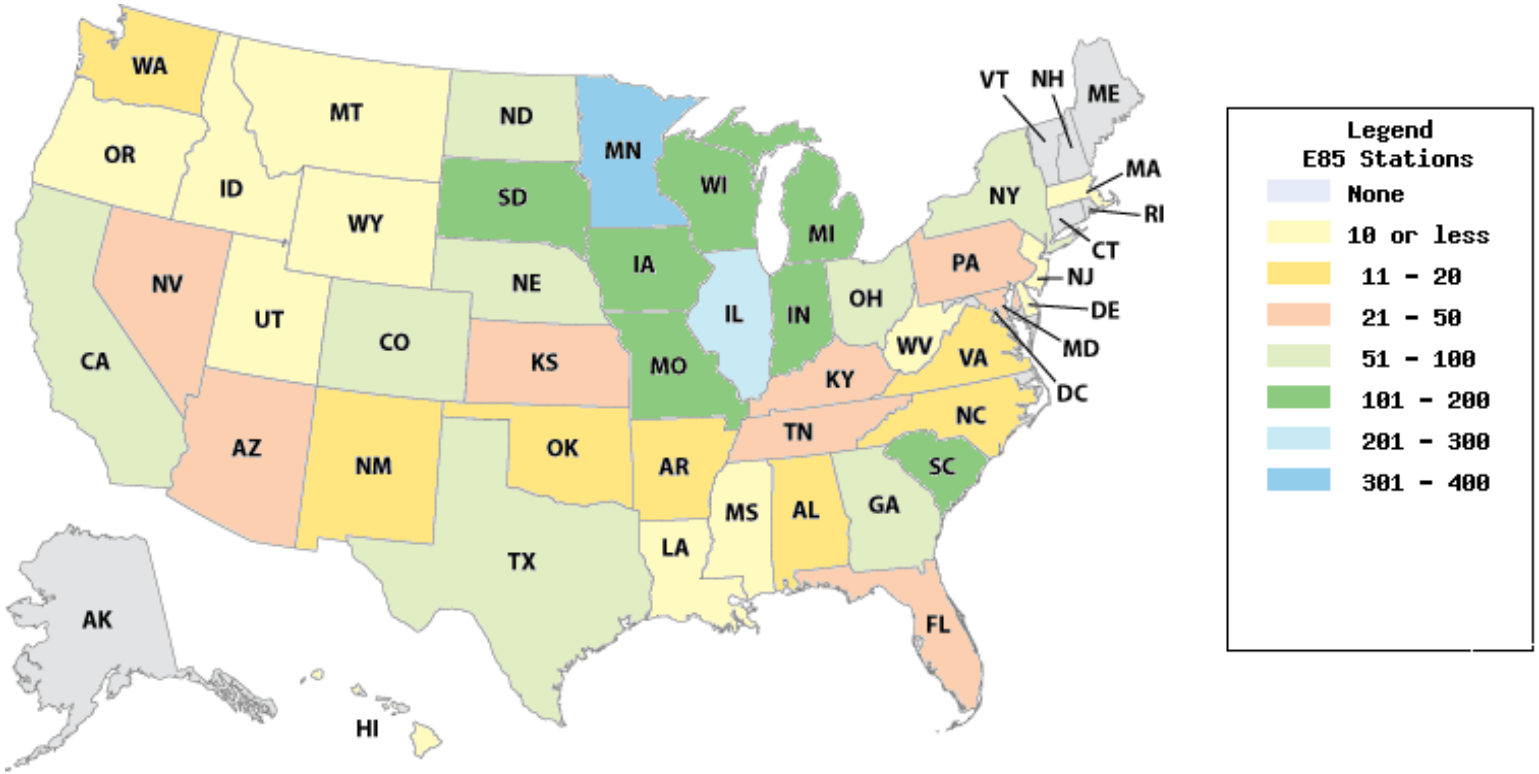
Trends in alternative fuel vehicles in the U.S.

Alternative fuelled vehicles in use



Approx. 9 Million LD vehicles sold in the US in 2009.
Approx. 8.35 Million Flex Fuel Vehicles in the US fleet in 2009.

Barriers for alternative fuels
E85



E85 predominant in the Midwest, where the majority of corn is grown in the US

US average prices (gal)*: Gasoline 3.68 $ E85 3.20 $

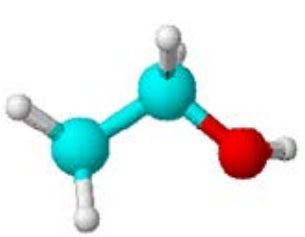
US average prices (GGE): Gasoline 3.68 $ E85 4.60 $

* Clean Cities Alternative Fuel Price Report. July 2011

Is butanol an alternative?

Fuel Specifications

		Gasoline	Ethanol	*iso*-Butanol
Chemical formula		C_4 - C_{12}	C_2H_5OH	C_4H_9OH
Composition (C, H, O)	Mass-%	86, 14, 0	52, 13, 35	65, 13.5, 21.5
Lower heating value	MJ/kg	42.7	26.8	33.1
Density	kg/m^3	715 - 765	790	802
Octane number ((R+M)/2)	-	90	100	103
Stoichiometric air/fuel ratio	-	14.7	9.0	11.2
Latent heat of vaporization	kJ/kg	380 – 500	919	686



Ethanol Blends	Fuel Oxygen (%-mass)	Butanol Blends
E10	**3.7**	**iso-But16**
E50	**18**	**iso-But83**

Constant oxygen mass content

Blend lower heating values

Gasoline: 42.7 MJ/kg

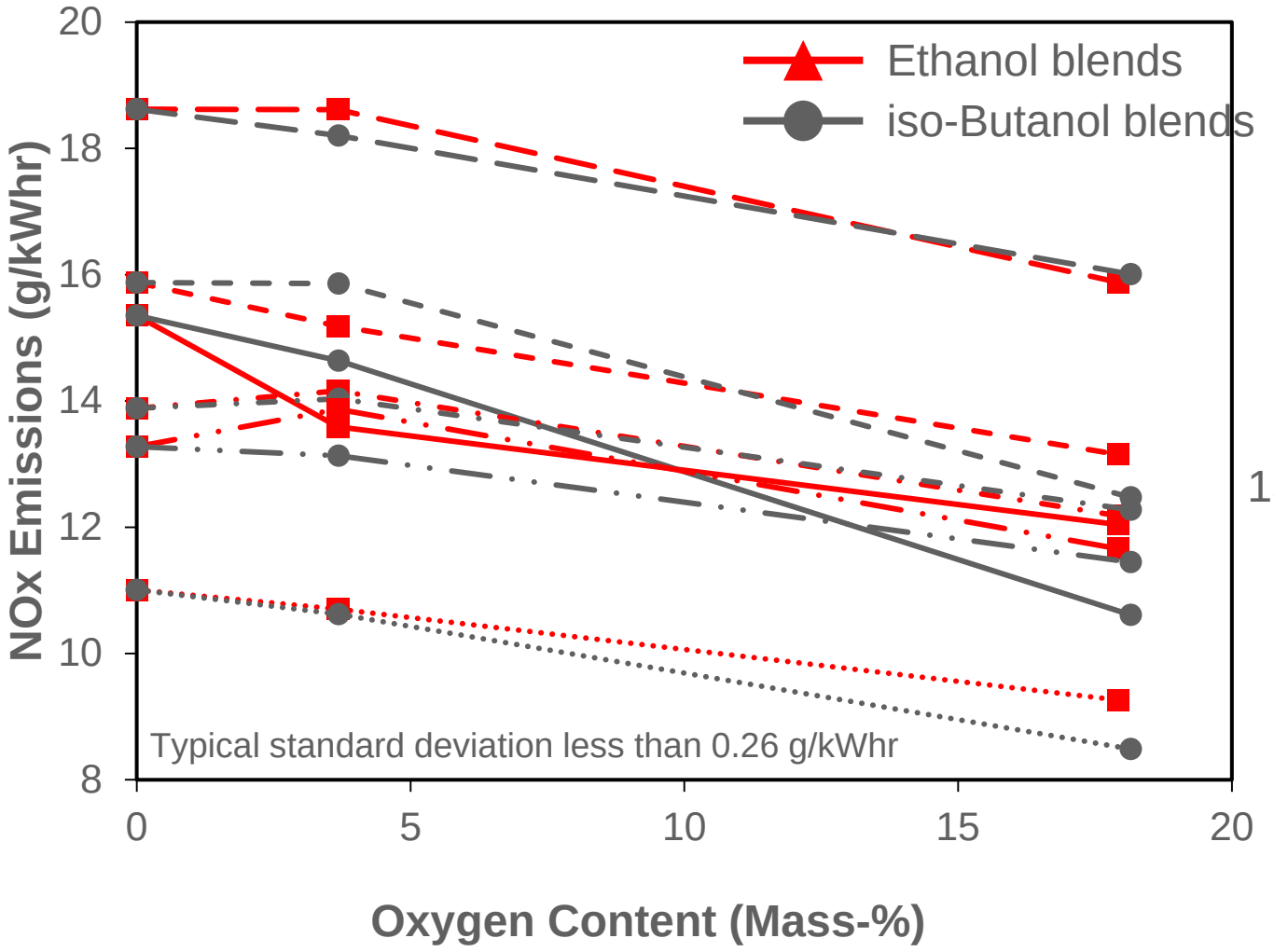
E10/B16: 41.0 MJ/kg

E50/B83: 34.5 MJ/kg

A joint venture between BP and DuPont

Butamax™ Advanced Biofuels LLC

Regulated emissions with butanol vs. ethanol

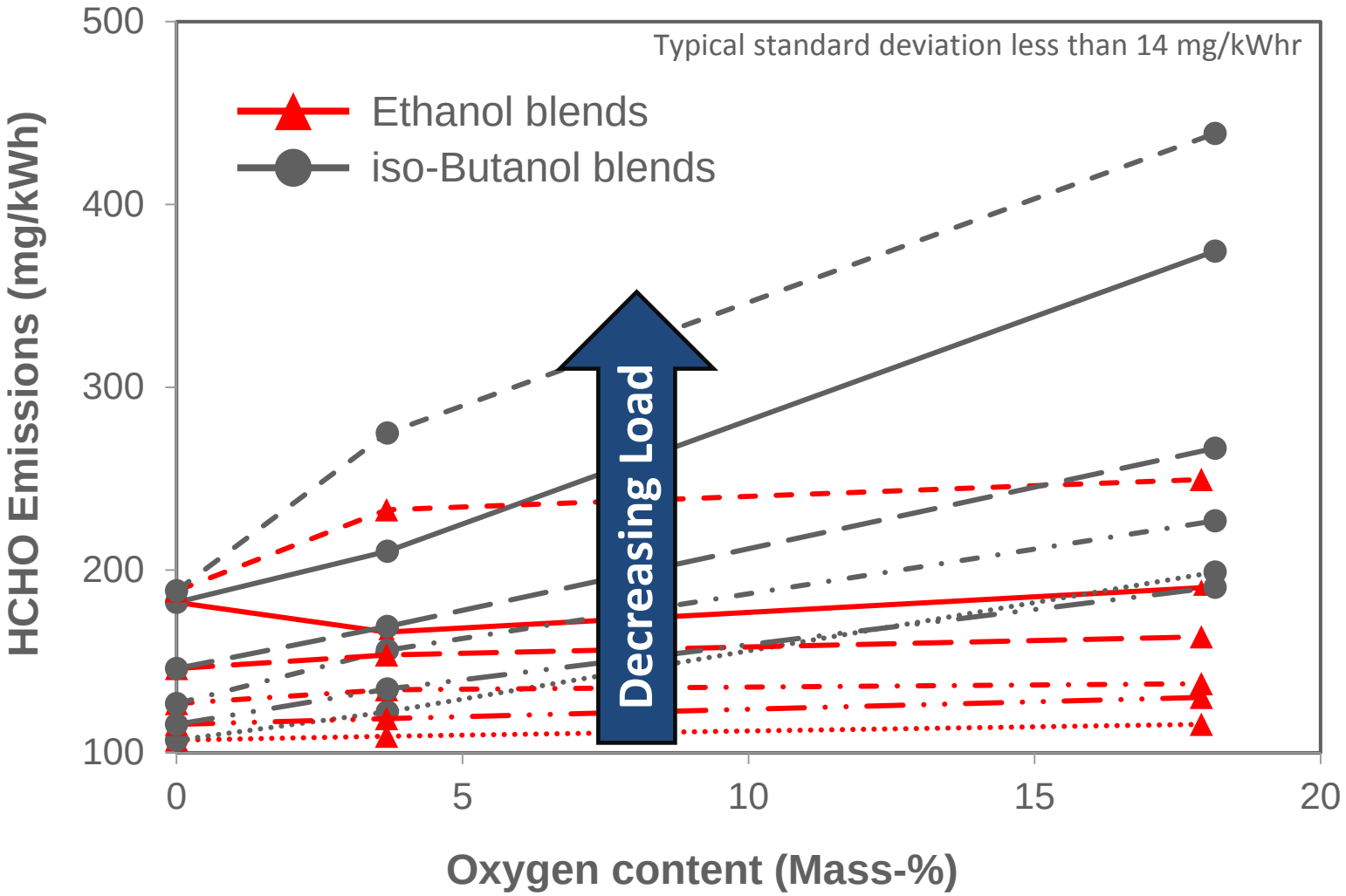


Operating Points

3000 rpm, 4 bar
2000 rpm, 2 bar
1500 rpm, 2.62 bar
2000 rpm, 6 bar
3000 rpm, 8 bar
1500 rpm, 8 bar

NOx decreases with increasing fuel alcohol and oxygen content

Formaldehyde emissions with butanol vs. ethanol

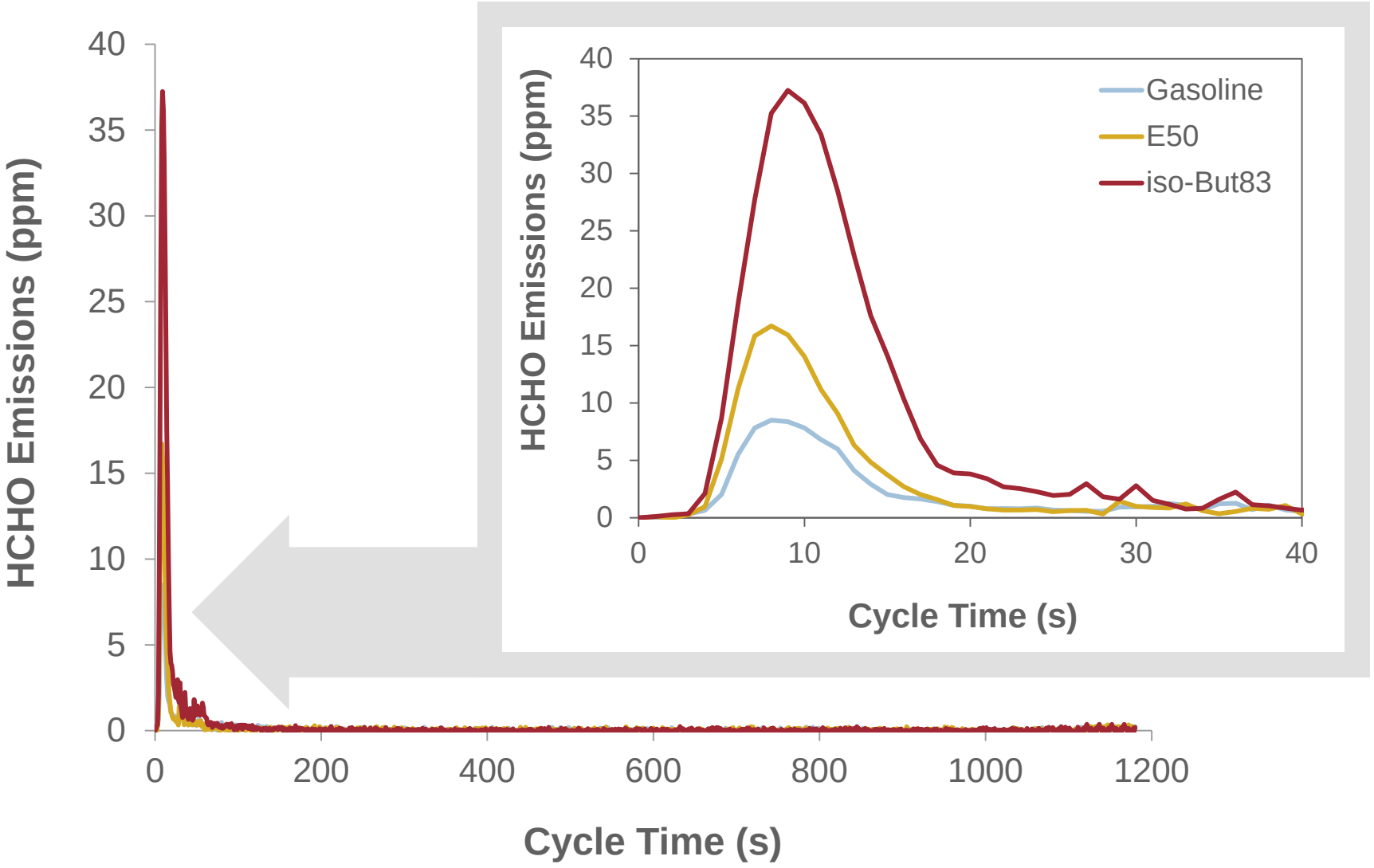


Operating Points

2000 rpm, 2 bar
1500 rpm, 2.62 bar
3000 rpm, 4 bar
2000 rpm, 6 bar
3000 rpm, 8 bar
1500 rpm, 8 bar

Increased formaldehye with *iso*-butanol blends, but not with ethanol blends

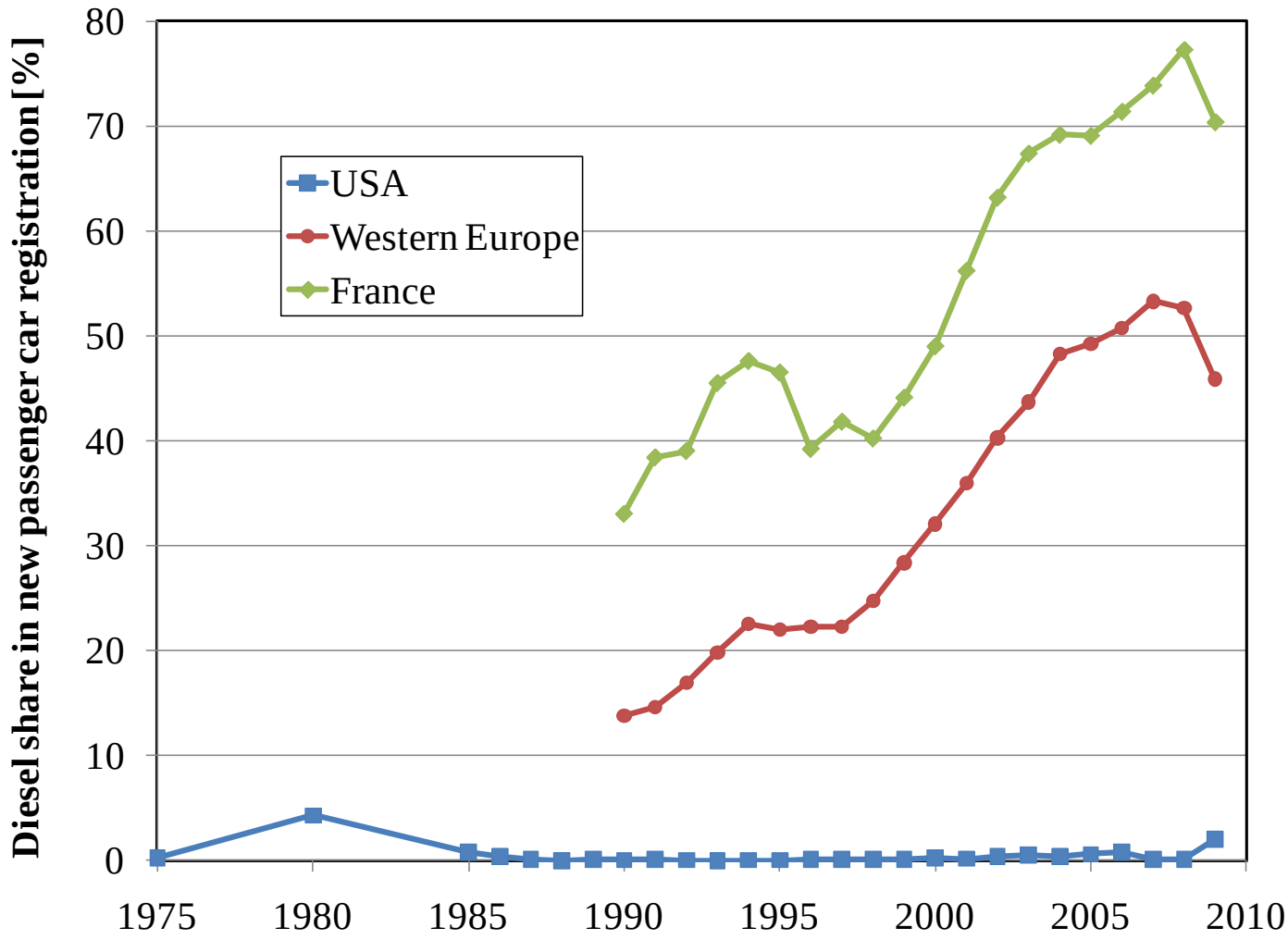
Formaldehyde Emissions: Cold-Start, Post-TWC



	Gasoline	E50	iso-But83
Cycle mass HCHO emitted (mg/km)	**1.5**	**2.0**	**7.0**

Diesel as an alternative for LD vehicles?

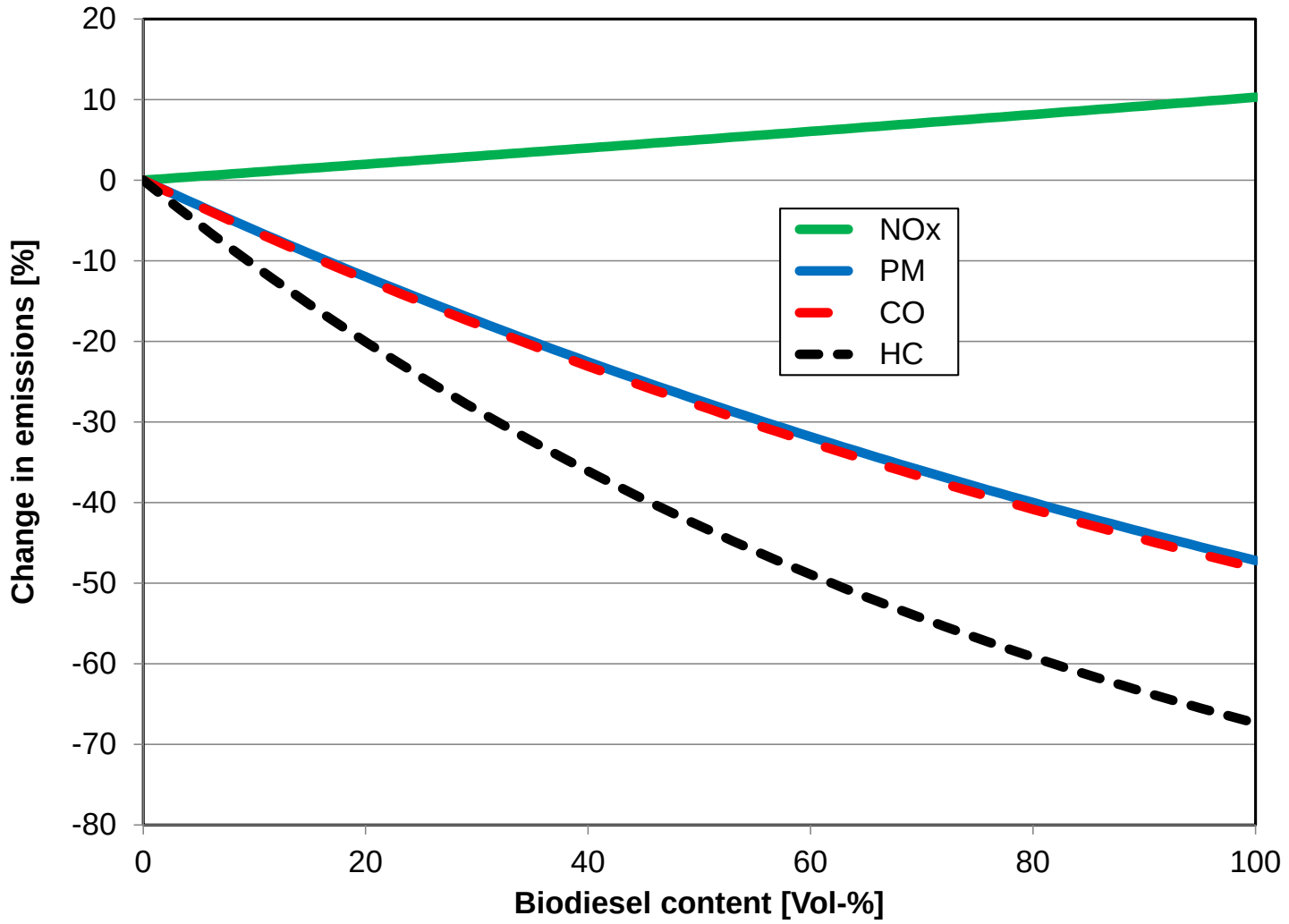
Diesel market share in Europe and the US…



In 2009, the United States produced 17.7% of the world's biodiesel, making it the 2nd largest producer behind Europe

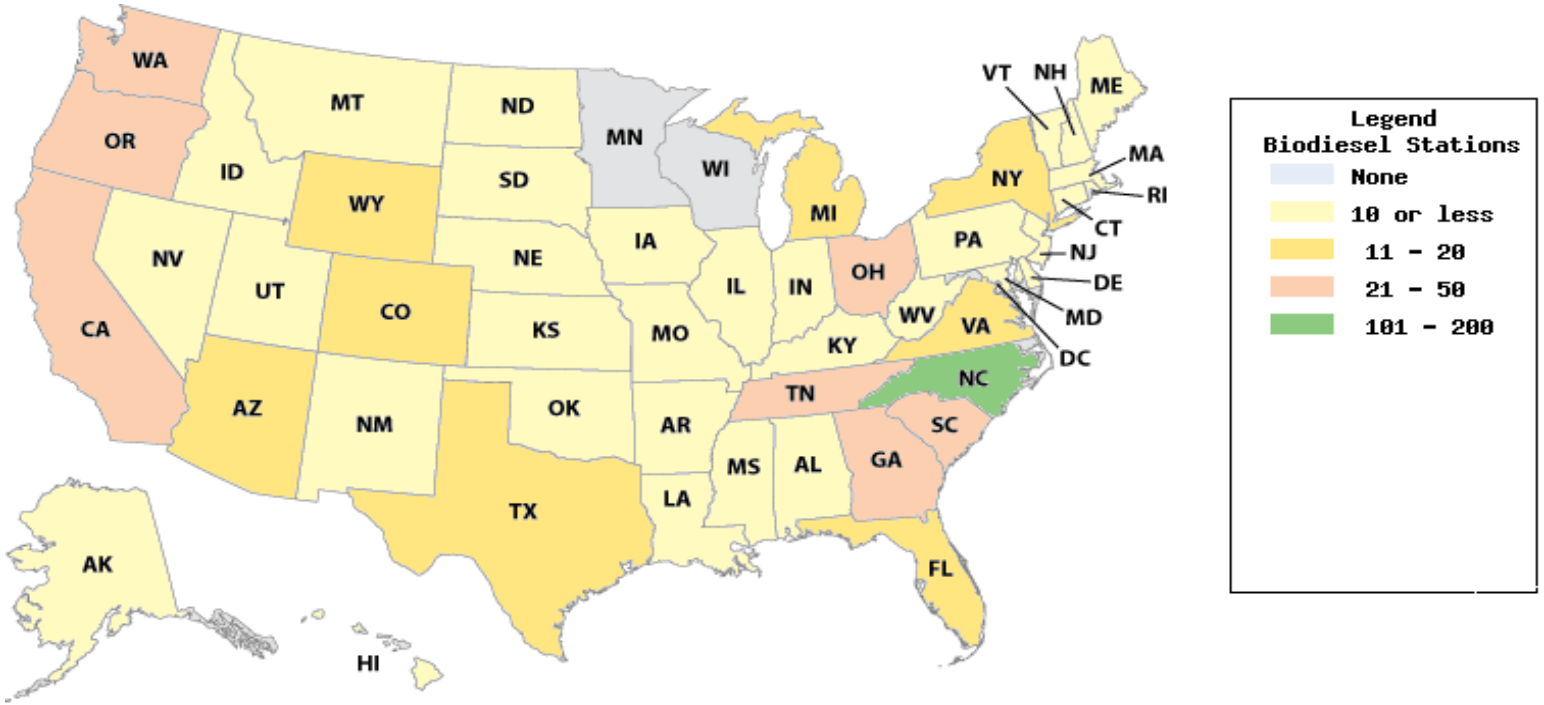
Impact of Biodiesel on emissions

Emissions versus biodiesel content



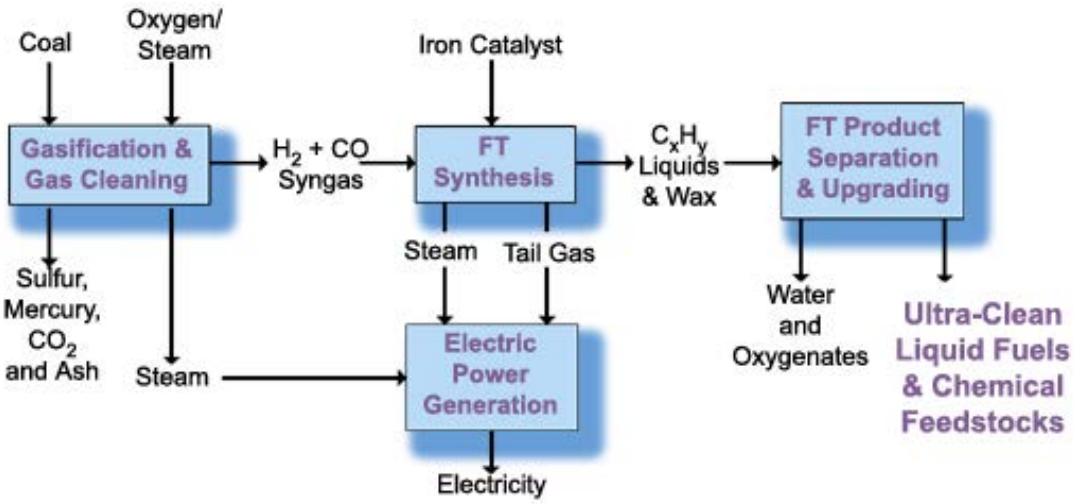
Influence of biodiesel content on regulated emissions is well studied and documented.

Barriers for alternative fuels
Biodiesel



North Carolina is the state with the largest number of Biodiesel stations possibly due the a Biodiesel Provider Credit. Although North Carolina has ¼ of the nations Biodiesel stations, the absolute number of 139 is not a significant fraction.

GTL/BTL/CTL (Gas/Biomass/Coal)
…to liquid



- Process of converting feedstock into high quality liquid fuels
- Most promising feedstocks are:
  - Natural gas
  - Biomass
  - Coal
- 27% of the world's known coal supplies are in the US
- In order to address greenhouse gas emissions concerns, carbon capture and sequestration measures have to be implemented

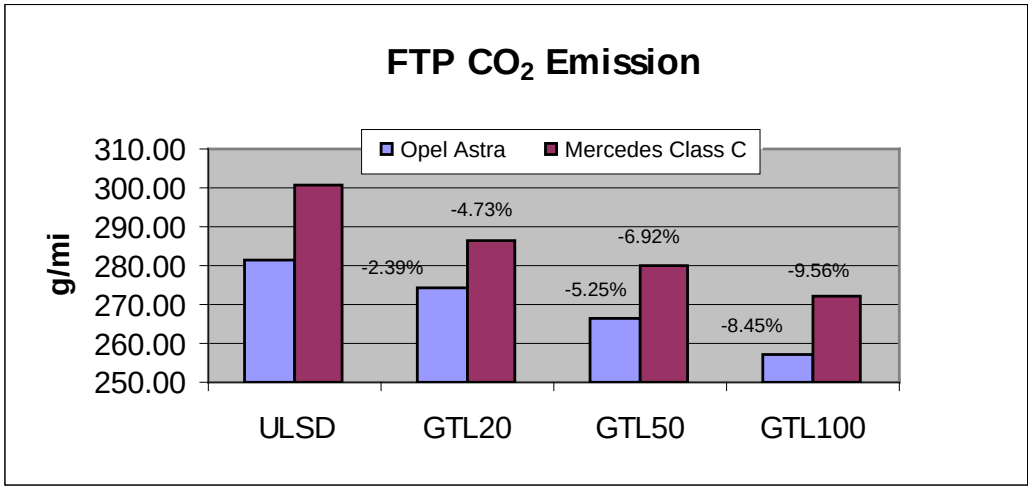
Source: www.futurecoalfuels.org

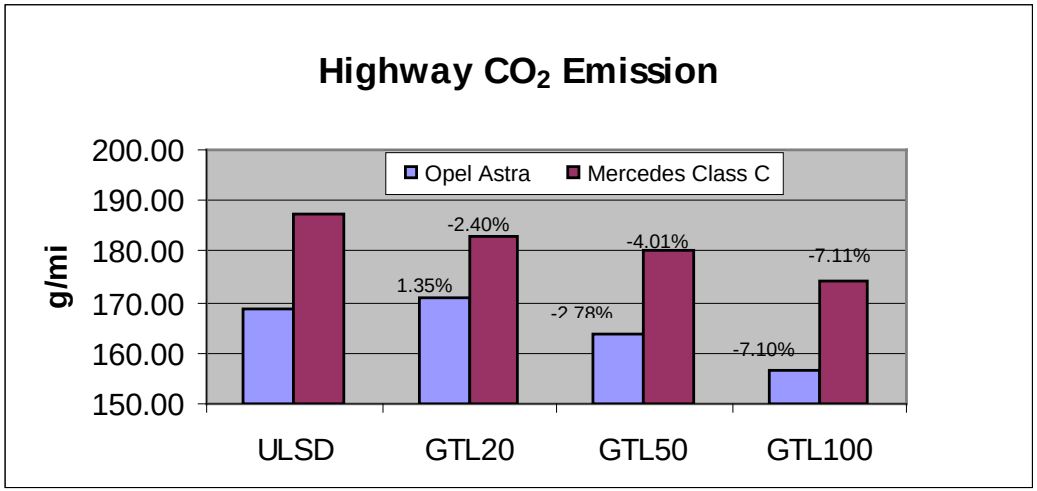
GTL/BTL/CTL (Gas/Biomass/Coal)
Potential users

- South Africa (Sasol) has been producing CTL for 50+ years and today covers ~30% of its fuel demand with CTL
- GTL was operated on a ferry during 2007
- Airbus completed first test flight of civil aircraft (A-380) on GTL in 2008

Source: www.gas2.org

GTL/ULSD Fuel Blend Performance
Effects on Older and Newer Vehicles

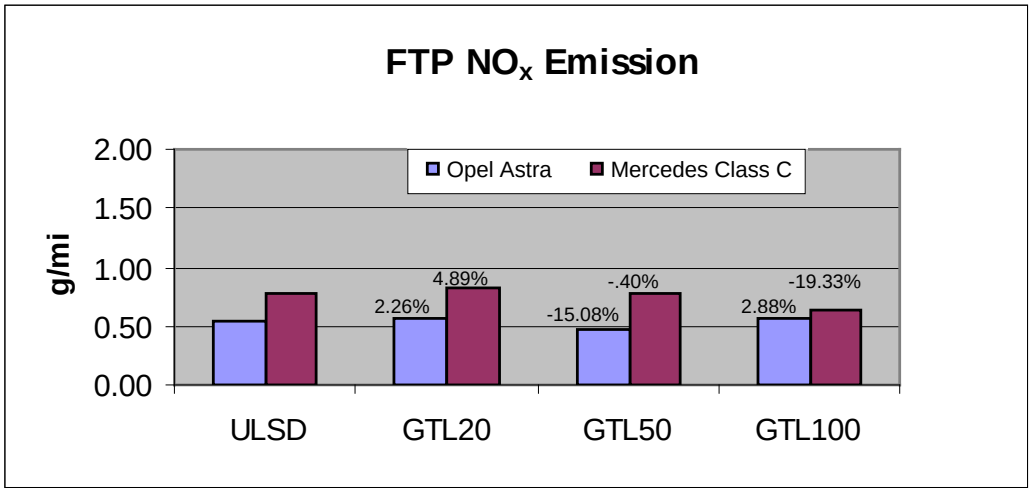


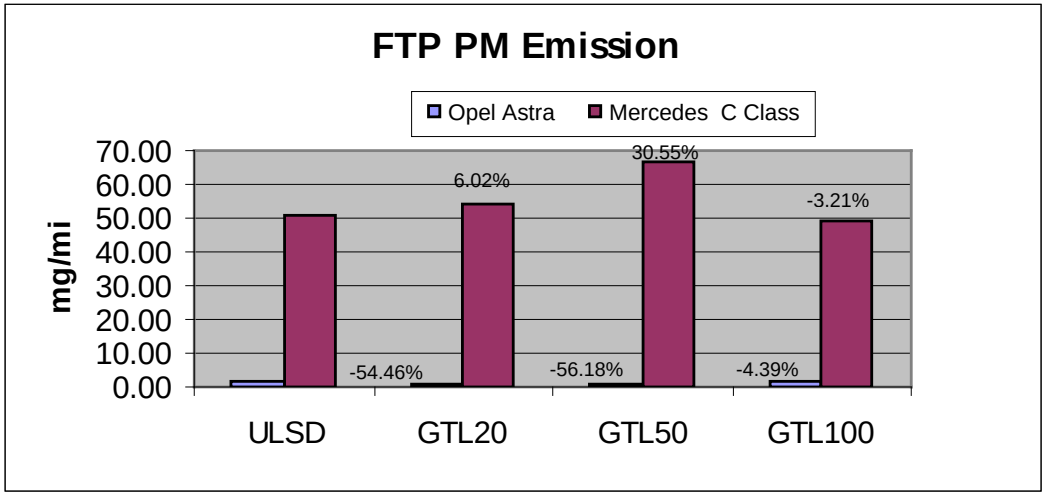


- Investigate and compare GTL/ULSD blends (0, 20, 50 and 100%) performance in an older (Mercedes C-Class 1999) and a newer (Opel Astra 2006)

GTL a drop-in fuel replacement. Reduced engine-out CO_2 emissions

GTL/ULSD Fuel Blend Performance
Effects on Older and Newer Vehicles

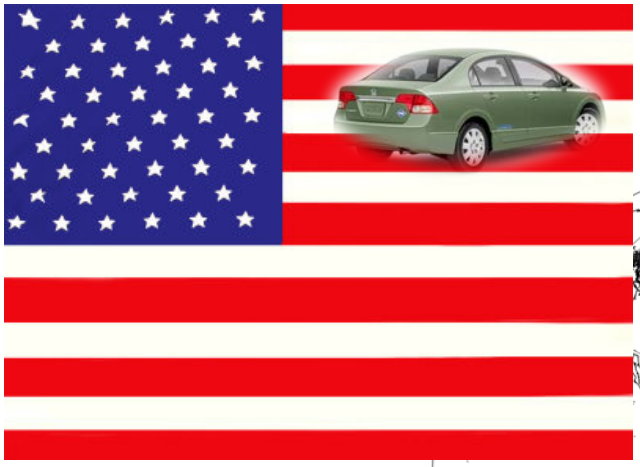




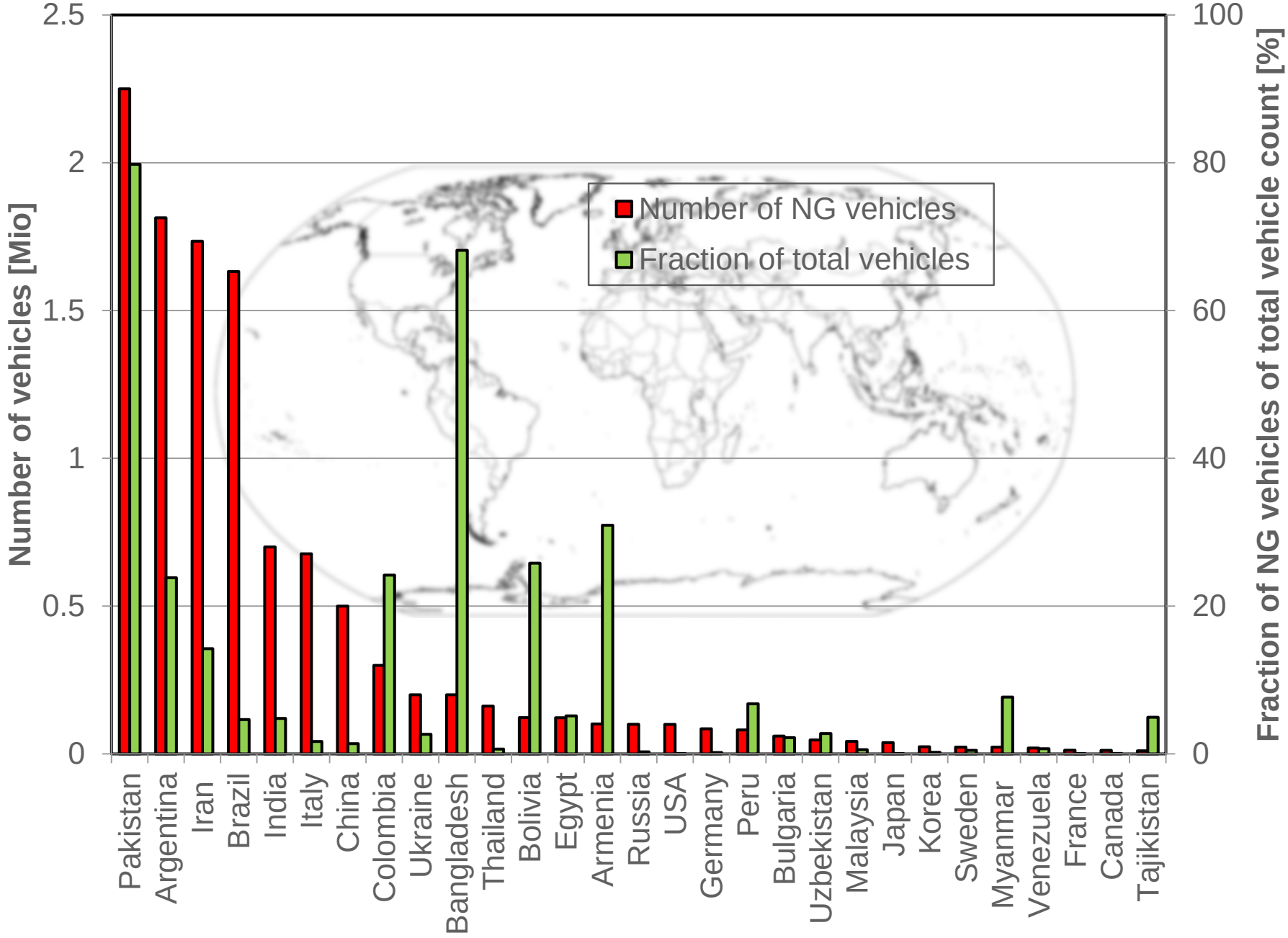
- Investigate and compare GTL/ULSD blends (0, 20, 50 and 100%) performance in an older (Mercedes C-Class 1999) and a newer (Opel Astra 2006)

Influence of GTL blending on NOx and PM emissions depends on vehicle technology

Status of CNG LD vehicles worldwide

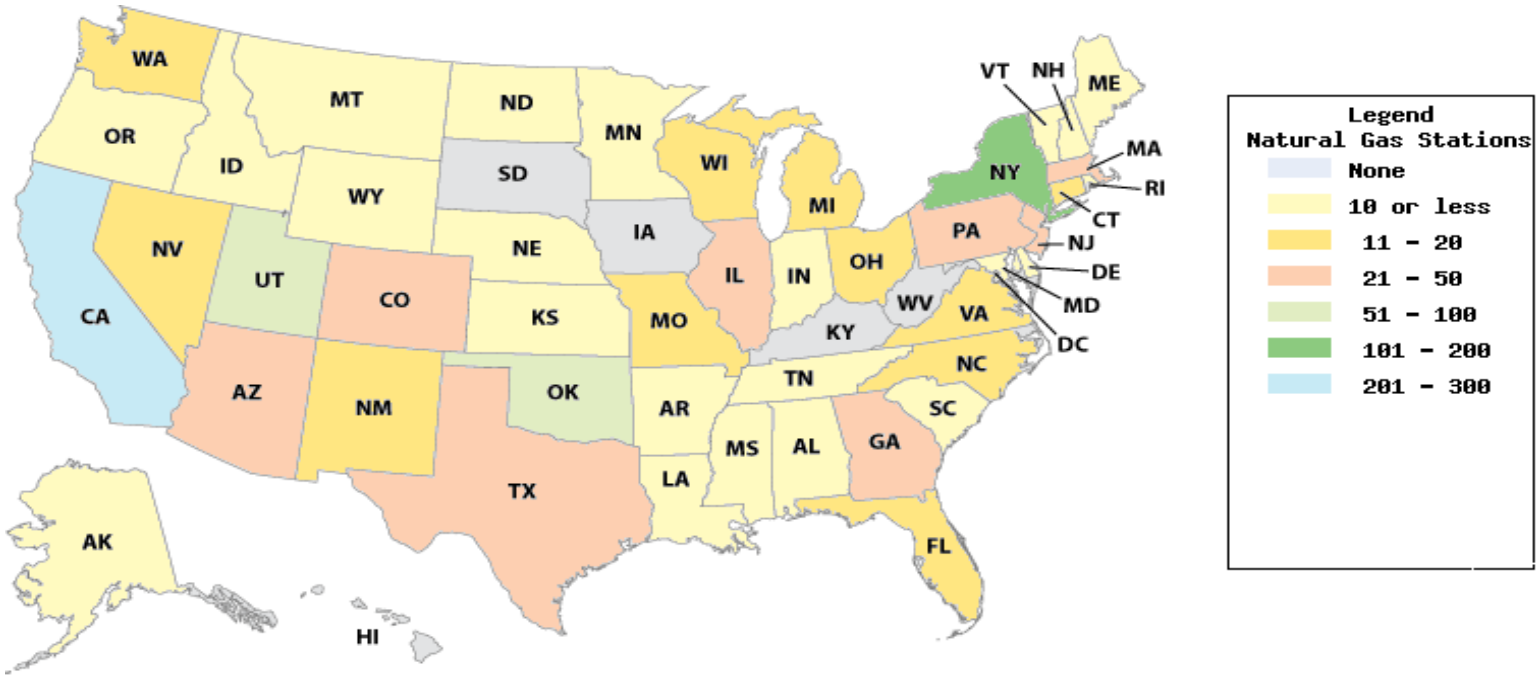


Status of CNG LD vehicles worldwide



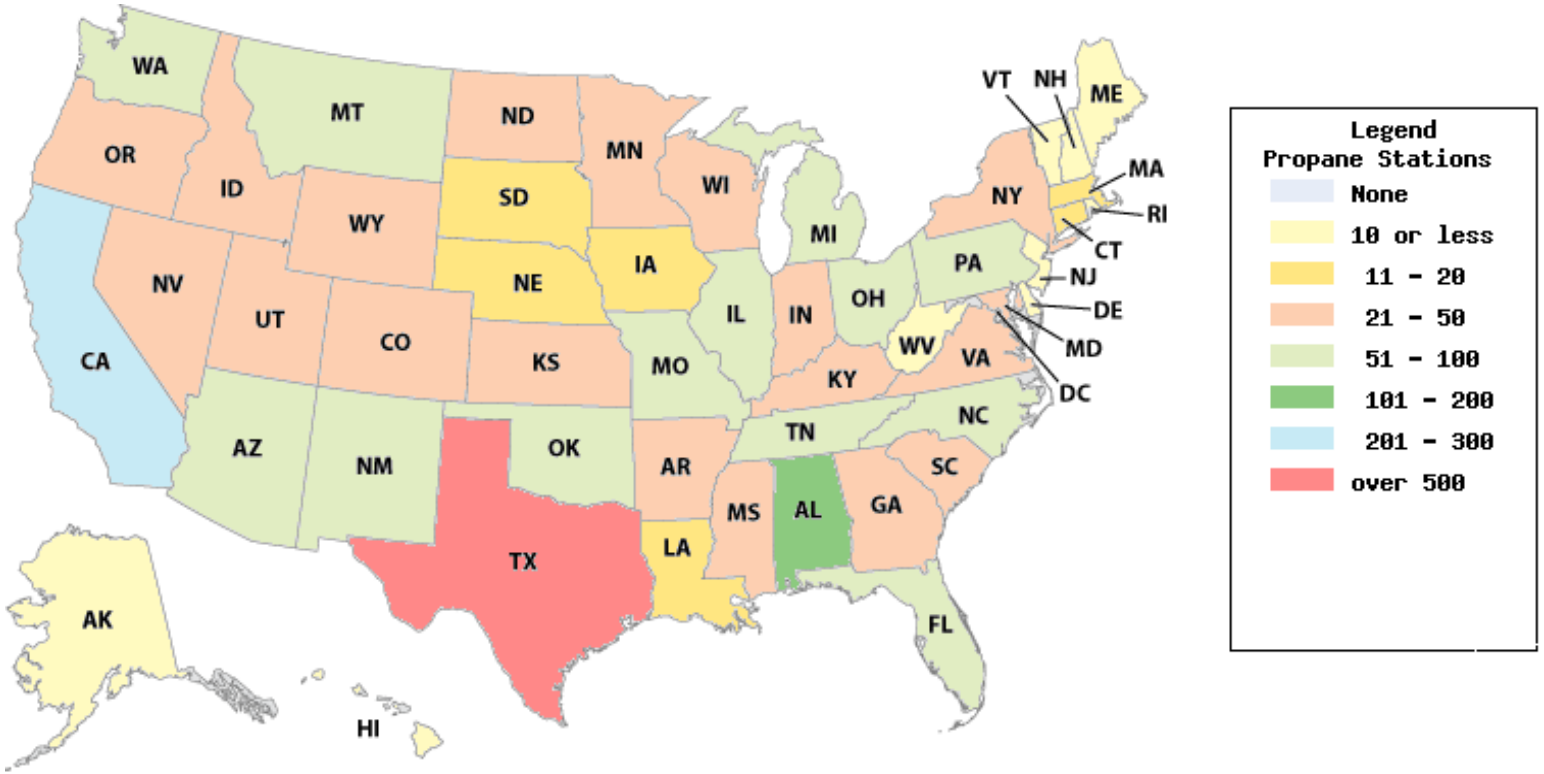
Source: NGVA Europe

Barriers for alternative fuels
Compressed Natural Gas (CNG)



Largest number of CNG stations is also in California linked to the use of NG by transit authorities promoted by California Natural Gas Vehicle Partnership (CNGVP). Honda Civic CNG has until now only been available in four states including California.

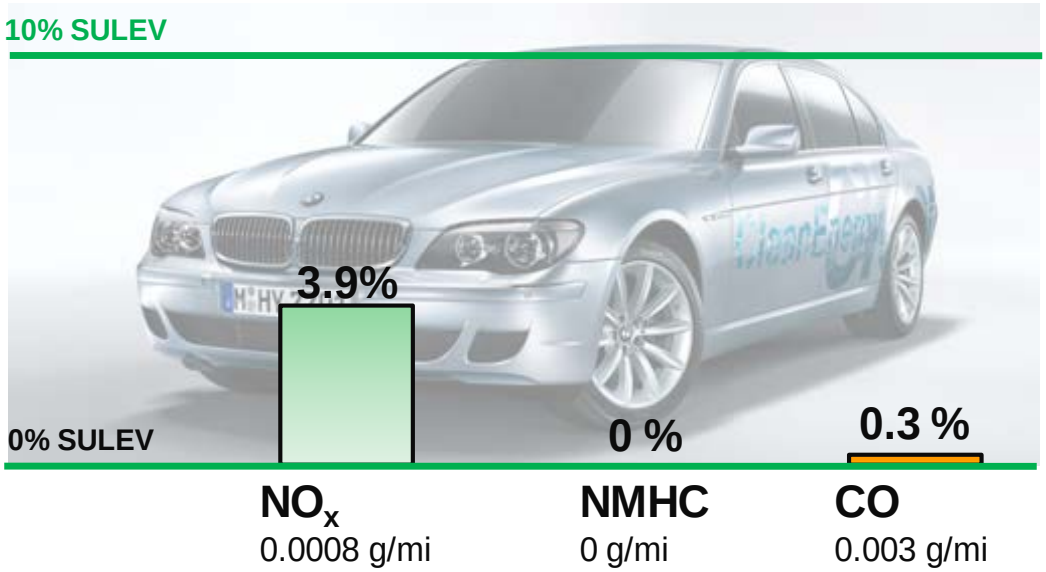
Barriers for alternative fuels
Propane (LPG)



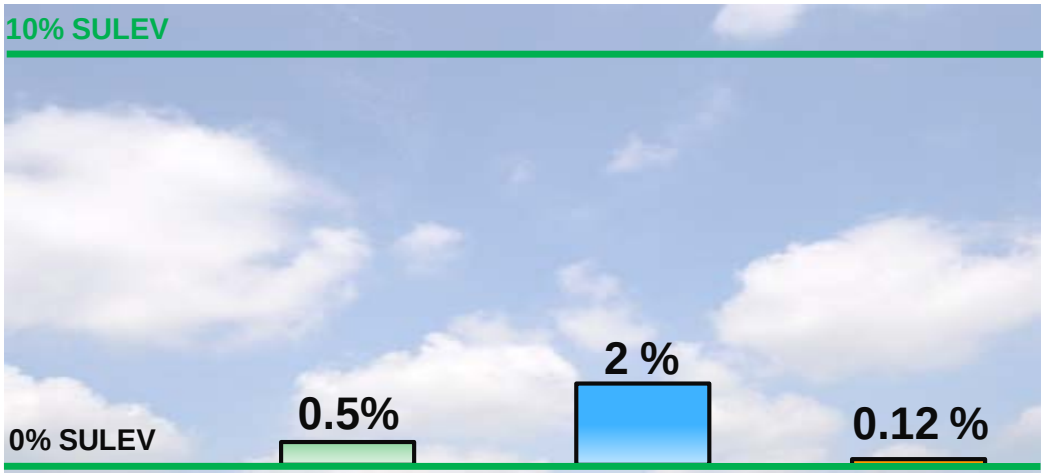
Texas has the largest propane infrastructure. Propane is a by-product of crude oil and NG refining and Texas has 36% of the nations refining capacity

Hydrogen an alternative?

Benchmarking of production hydrogen vehicles



* Average values for several FTP75 tests on two vehicles

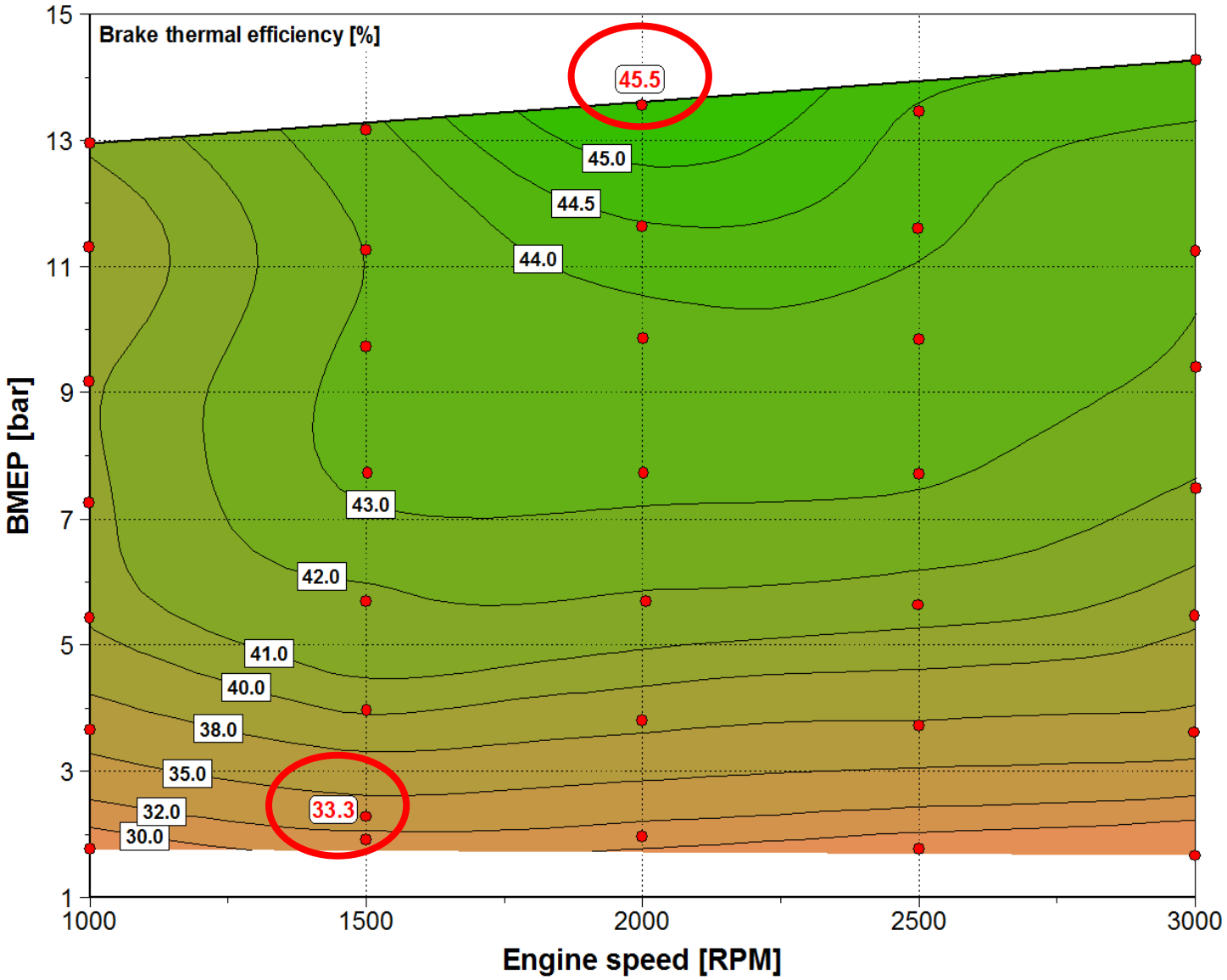


* One test case; values change with background concentration

- BMW Hydrogen 7 Mono-Fuel Demonstration Vehicle
- Emissions levels of hydrogen vehicles are close to ambient
- Hydrogen engine vehicle could act as a bridging technology for infrastructure development
- Hydrogen-CNG blends as potential driver

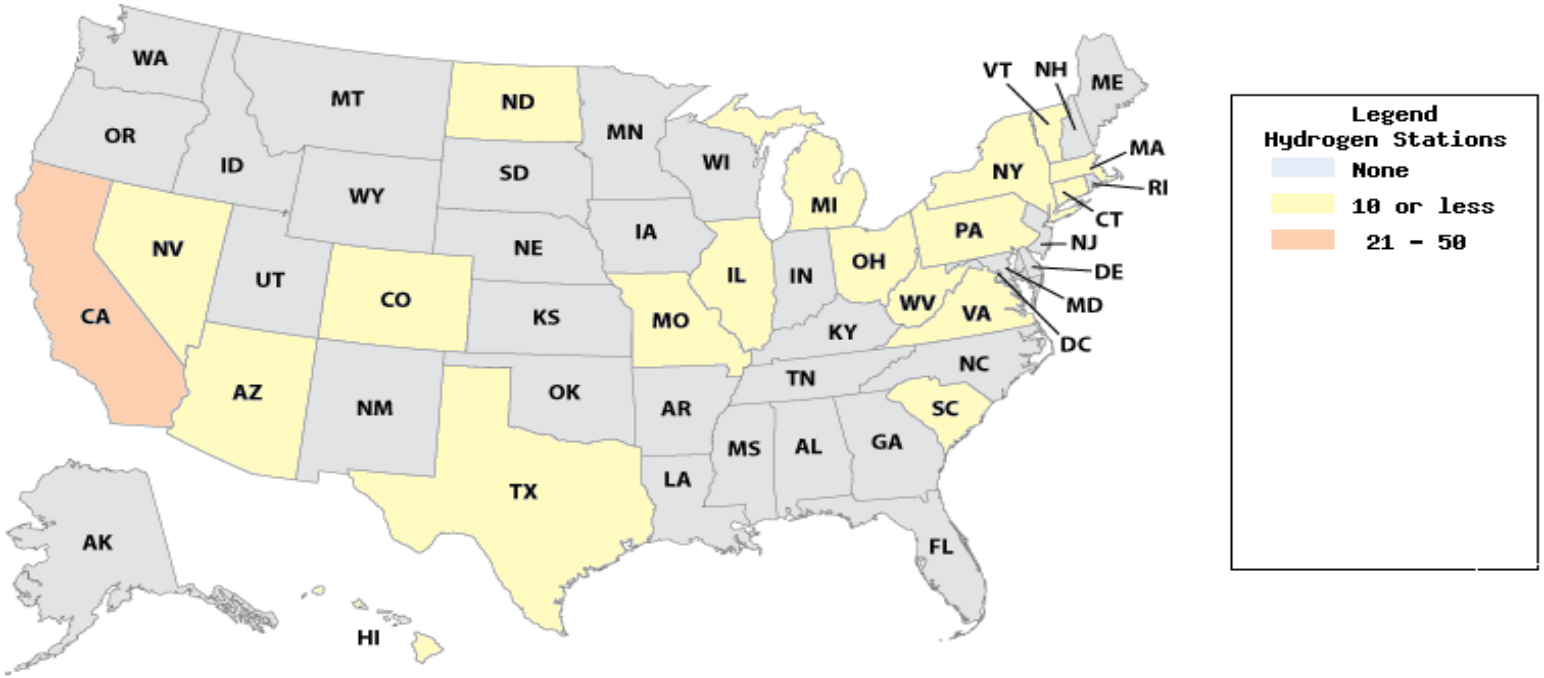
Efficiency potential of hydrogen engines

Brake thermal efficiency results



- **Peak BTE**
  - Target: 45%
  - **Actual: 45.5%**
- **BTE at WWMP**
  - Target: 31%
  - **Actual: 33.3%**
- **Performance**
  - **14.3 bar BMEP**

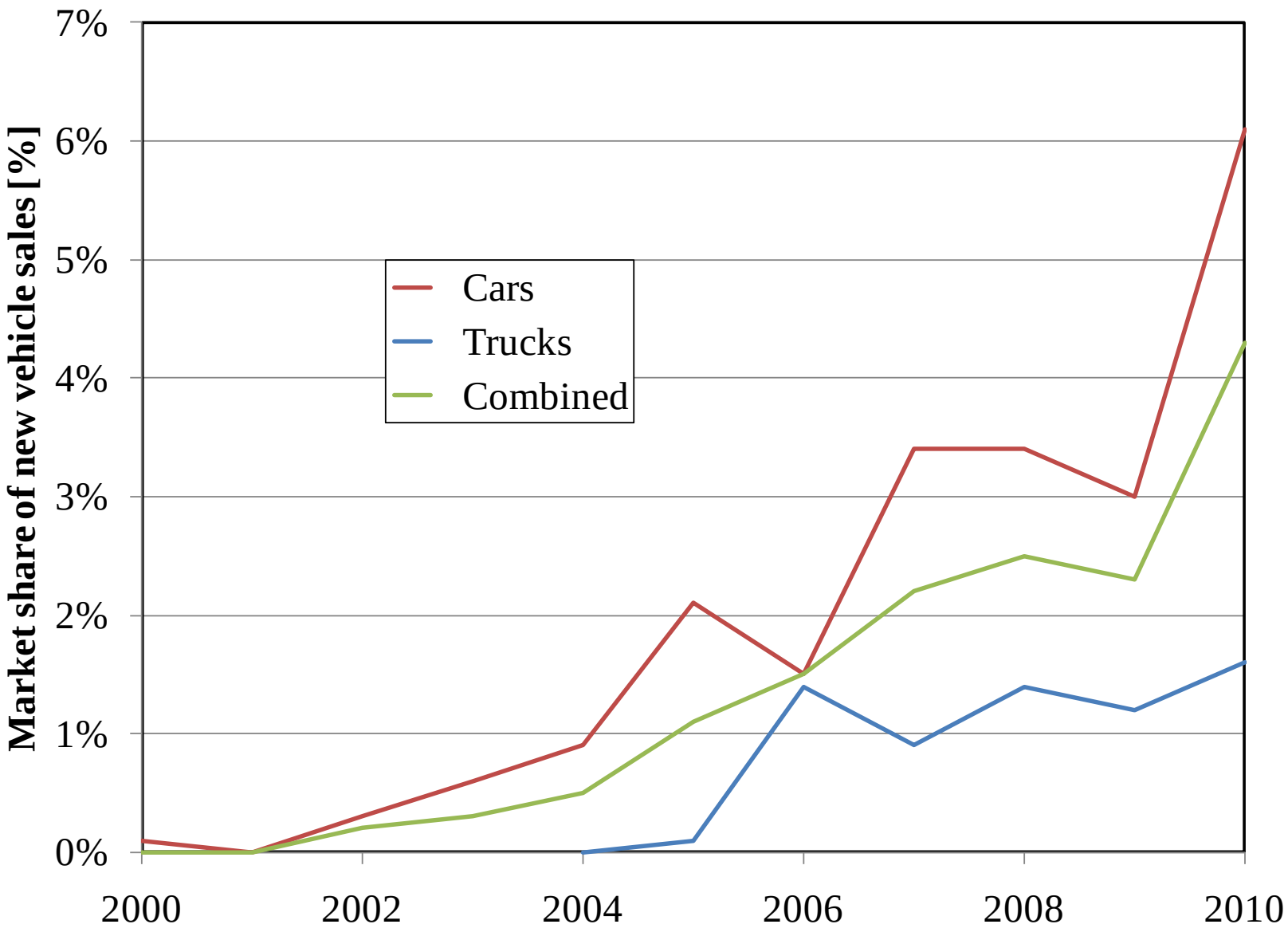
Barriers for alternative fuels
Hydrogen (H_2)



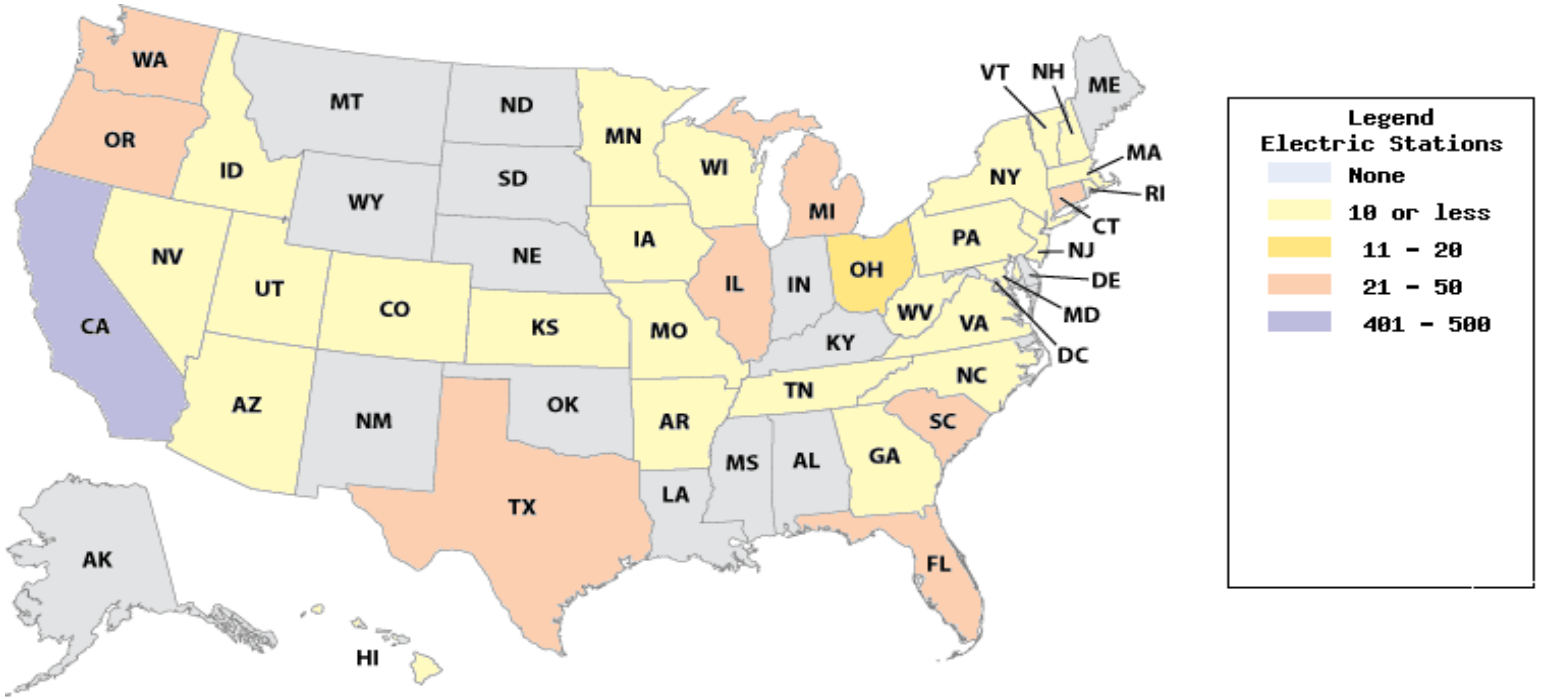
California is the only state with a significant number of H_2 stations mainly due to the ZEV mandate. H_2 is promoted by the California Fuel Cell Partnership and the Hydrogen Highway Network

Vehicle electrification…

Development of market share of hybrid vehicles in the US



Barriers for alternative fuels
Electricity



Charging station development in California started in the 1990s. First generation of electric vehicles never saw significant sales.

Vehicle electrification…
A PEV (Plug-in electric vehicle) scenario

*"With more research and incentives, we can break our dependence on oil with biofuels, and become the first country to have a **million electric vehicles on the road by 2015**"*
President Barack Obama, 2011 State of the Union
(240 Million vehicles are on the road in USA)

Estimated U.S. supply of PEVs from 2011-2015						
Manufacturer and model	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
Fisker Karma PHEV	1,000	5,000	10,000	10,000	10,000	36,000
Fisker Nina PHEV		5,000	40,000	75,000	75,000	195,000
Ford Focus EV		10,000	20,000	20,000	20,000	70,000
Ford Transit Connect EV	400	800	1,000	1,000	1,000	4,200
GM Chevrolet Volt	15,000	120,000	120,000	120,000	120,000	505,000
Navistar eStar EV (truck)	200	800	1,000	1,000	1,000	4,000
Nissan LEAF EV	25,000	25,000	50,000	100,000	100,000	300,000
Smith Electric Vehicles Newton EV (truck)	1,000	1,000	1,000	1,000	1,000	5,000
Tesla Motors Model S EV		5,000	10,000	20,000	20,000	55,000
Tesla Motors Roadster EV	1,000					1,000
Think City EV	2,000	5,000	10,000	20,000	20,000	57,000
Cumulative Total						**1,222,200**

Note: The above numbers have been taken from announced produciton figures and media reports. In some cases more conservate estimates have been used due to: delays that have occurred since

Major PEV infrastructure development

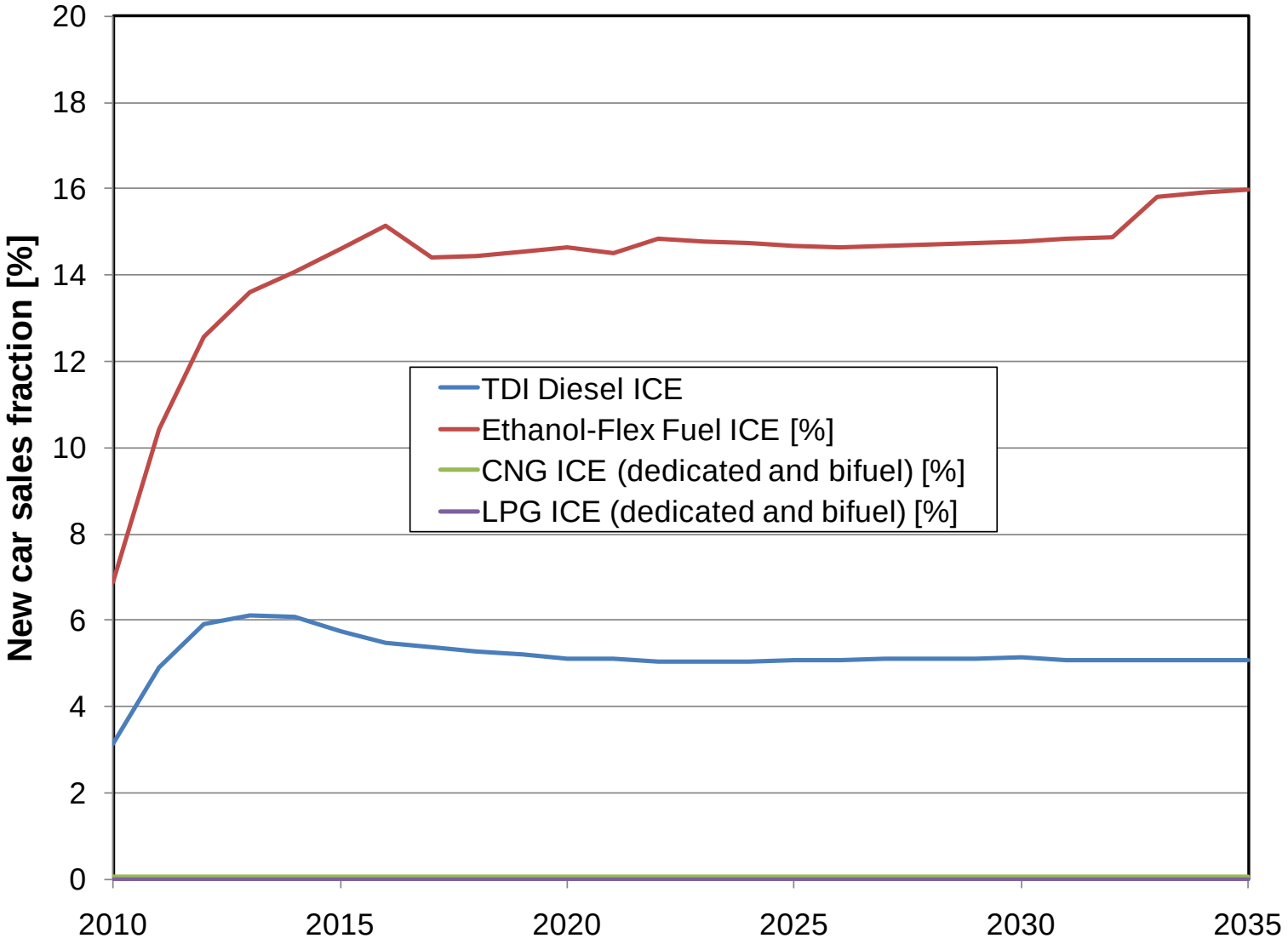
Total ARRA funding estimated at $2 billion

Company	Award	Details
Electric Transportation Engineering Corporation	$ 114.8 M	- *Collect data from 7,500 Nissan Leaf BEVs and Chevy Volt PHEVs* - *Deploy 15,000 Level 2 charging stations, 250 Level 3* - *Full instrumentation of vehicles and infrastructure for analysis*
Chrysler, LLC$	48 M	- *Develop 140 PHEV Ram Pickups* - *Deploy in partner fleets across a wide range of climates, environments*
South Coast Air Quality Management District	$ 45.4 M	- *Development of a production PHEV system for Class 2-5 vehicles* - *Demonstration of 378 trucks through partner fleets*
Coulomb Technologies	$ 15 M	- *Deployment of ~4000 public and private charging stations in up to 9 cities*
Navistar	$ 39.2 M	- *Develop and deploy 950 battery electric trucks with 100 miles range*
Cascade Sierra Solution	$ 22.2 M	- *Deploy truck stop electrification at 50 sites along major US interstates*
General Motors	$ 30.5 M	- *Develop demonstrate 125 Chevy Volts for electric utilities,500 Volts to consumers*
Smith Electric Vehicle	$ 32 M	- *Develop and deploy up to 500 medium-duty electric trucks* - *Deploy in partner fleets across a wide range of climates, environments*

Further challenges include PEV test procedures and Fuel Economy Labeling

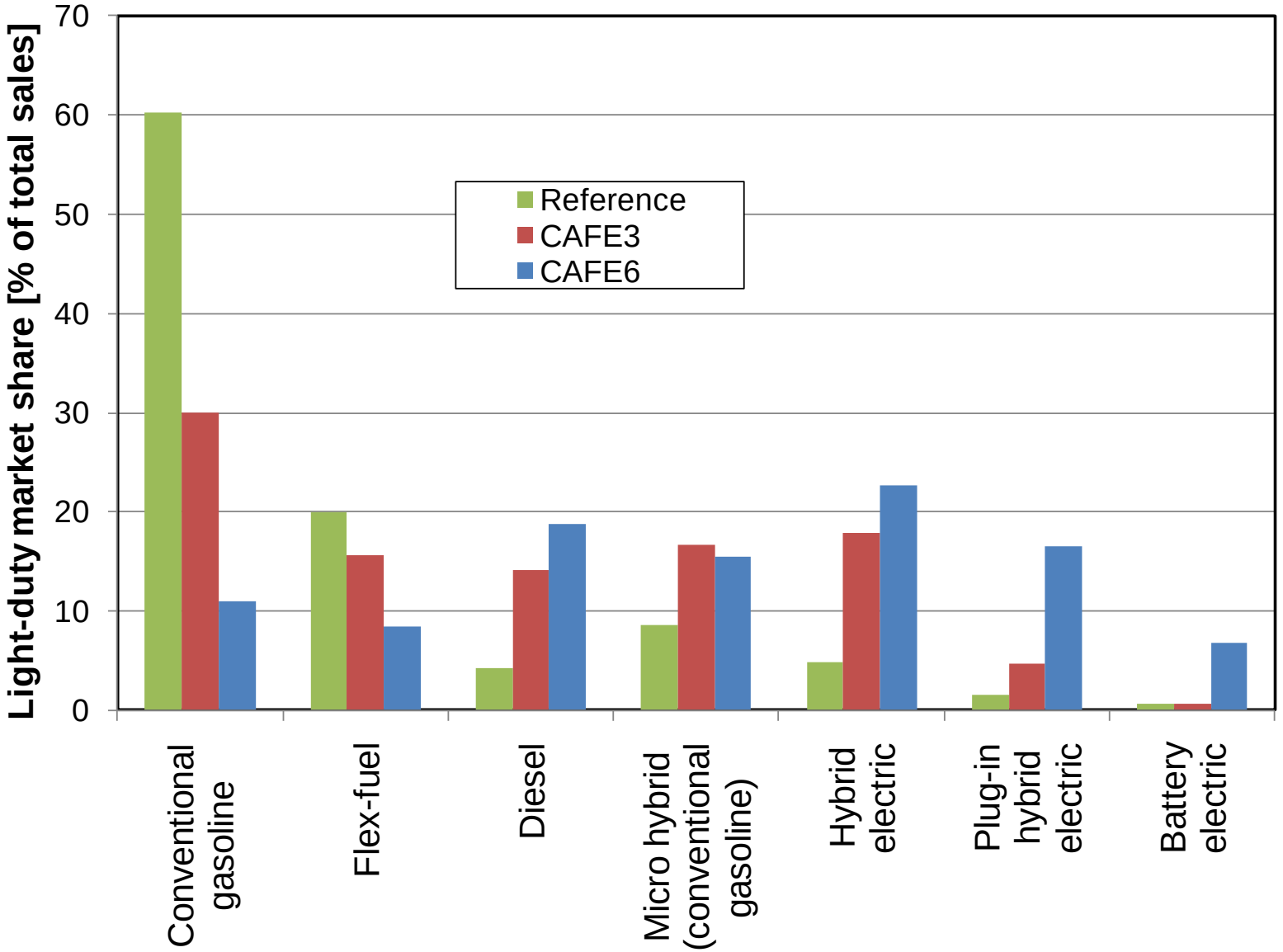
A glimpse in the future…

Predicted market share of alternative fuel cars in the US



Influence of regulations on market share

Projected market share of advanced vehicles in 2025



Source: US EIA Annual Energy Outlook 2011

Summary and conclusions
(White House) Initiatives

Electrification (Plug-In)


*"With more research and incentives, we can break our dependence on oil with biofuels, and become the first country to have a **million electric vehicles on the road by 2015**"*
- President Barack Obama, 2011 State of the Union
(240 Million vehicles are on the road in USA)

Domestic fuel sources

*"By 2025 – we will have **cut imported oil by one-third**. "*
*"The Administration is committed to the use of this important domestic resource **[Natural Gas]**"*
- President Barack Obama, Talk on Energy at Georgetown University March 30, 2011

E15 waiver

Renewable fuels standard (RFS)

CAFE regulations

→*Approach: more bullets, not silver bullets*

ALTERNATIVE FUELS FOR TRANSPORTATION - THE QUEST FOR THE SILVER BULLET…

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